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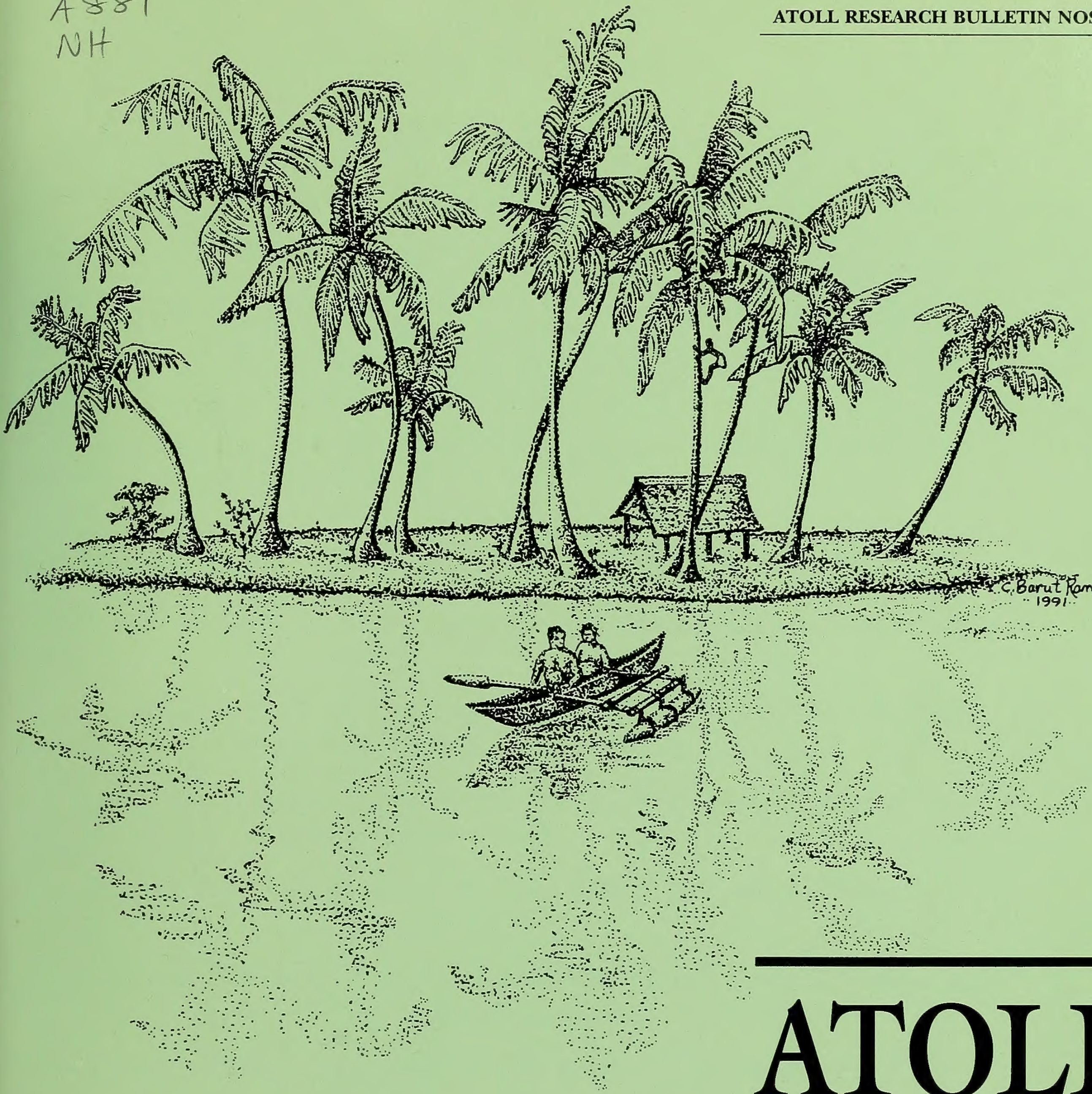

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NOS. 450-458

NO. 450. DEVELOPMENT OF BIOLOGICAL CRITERIA FOR CORAL REEF ECOSYSTEM ASSESSMENT
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SMITHSONIAN INSTITUTION
WASHINGTON, D.C., U.S.A.
SEPTEMBER 1998

ACKNOWLEDGMENT

The Atoll Research Bulletin is issued by the Smithsonian Institution to provide an outlet for information on the biota of tropical islands and reefs and on the environment that supports the biota. The Bulletin is supported by the National Museum of Natural History and is produced by the Smithsonian Press. This issue is partly financed and distributed with funds from Atoll Research Bulletin readers and authors.

The Bulletin was founded in 1951 and the first 117 numbers were issued by the Pacific Science Board, National Academy of Sciences, with financial support from the Office of Naval Research. Its pages were devoted largely to reports resulting from the Pacific Science Board's Coral Atoll Program.

All statements made in papers published in the Atoll Research Bulletin are the sole responsibility of the authors and do not necessarily represent the views of the Smithsonian nor of the editors of the Bulletin.

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Development of Biological Criteria for Coral Reef Ecosystem Assessment

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DEVELOPMENT OF BIOLOGICAL CRITERIA

FOR

CORAL REEF ECOSYSTEM

ASSESSMENT

BY

STEPHEN C. JAMESON[1], MARK V. ERDMANN[1], GEORGE R. GIBSON, JR.[2] AND
KENNARD W. POTTS[2]

PREFACE

The following paper is derived from a meeting of coral reef specialists held in Annapolis, Maryland on 16 and 17 January 1995. The title and purpose of that symposium was to discuss ... "practical, reliable, low cost monitoring methods for assessing the biota and habitat conditions of coral reefs". A recommendation of that meeting was to further explore the need for a technical guidance document to provide the basis for using biocriteria to assess the condition of coral reef habitats.

This paper was consequently prepared to further investigate the feasibility of writing a detailed technical guidance manual for the development of biological criteria (biocriteria) for coral reef ecosystems. Such criteria are "benchmark measurements" of the condition of resident aquatic communities which EPA and others can use to make management decisions including the development of EPA standards and regulations for the protection and restoration of these resources.

This study which follows does not present official Agency policy, rather it is an evaluation of the scientific and practical utility of preparing such a manual. Comments and suggestions from readers of the Atoll Research Bulletin to this exploratory manuscript will be appreciated and may be addressed to George Gibson and Kennard Potts, US Environmental Protection Agency Laboratory, 839 Bestgate Road, Annapolis, MD 21401.

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Manuscript received 30 June 1998; revised 31 July 1998

INTRODUCTION

PURPOSE OF THIS PAPER

The purpose of this paper is to provide the United States Environmental Protection Agency (EPA) with advice on the feasibility of establishing biological criteria for assessing coral reef ecosystems. Following up on the conclusions and next steps presented in: *A Coral Reef Symposium on Practical, Reliable, Low Cost Monitoring Methods for Assessing the Biota and Habitat Conditions of Coral Reefs* (Crosby et al. 1996), we address the following questions.

- Does sufficient need exist to justify preparation of a guidance document on the development of coral reef ecosystem biocriteria?
- Does sufficient information currently exist to draft this guidance?
- What data, research and/or projects are needed to facilitate development of such a guidance document?

Because of the interconnections which can develop between coral reefs, seagrass beds and mangrove forests, these ecosystems are considered one for the purposes of coral reef ecosystem bioassessment and biocriteria development described here. (If future assessment shows that it is not feasible to combine these habitats for the purpose of biocriteria development, then the definition of coral reef ecosystem will be changed accordingly.)

The biogeographic focus of this paper is coral reef ecosystems under U.S. jurisdiction. Coral reef ecosystems under United States jurisdiction are defined as ecosystems in waters where any United States environmental regulations apply and does not imply that the United States Federal government subsumes jurisdiction within the territorial sea.

Table 1 lists those coral reef ecosystems under US jurisdiction (see Figures 1 and 2 for geographic locations). The coral reef ecosystems of the Florida Reef Tract, the Flower Garden Banks in the Gulf of Mexico, and Fagatele Bay, American Samoa receive some degree of protection as National Marine Sanctuaries.

Table 1: Coral reef ecosystems under United States jurisdiction.

Western Atlantic	Gulf of Mexico	Caribbean	Pacific
Florida Reef Tract	Flower Gardens Banks	Puerto Rico	Hawaiian Islands
		US Virgin Islands	Line Islands - Palmyra Island, Kingman Reef, Johnson Atoll, Howland Island, Baker Island, Jarvis Island
			American Samoa
			Wake Island
			Mariana Islands - 14 islands including Guam

Figure 1. Coral reef ecosystems under United States jurisdiction in the western Atlantic Ocean, Gulf of Mexico and Caribbean Sea are found around: the Florida Reef Tract; Flower Gardens Banks; Puerto Rico; and the U.S. Virgin Islands.

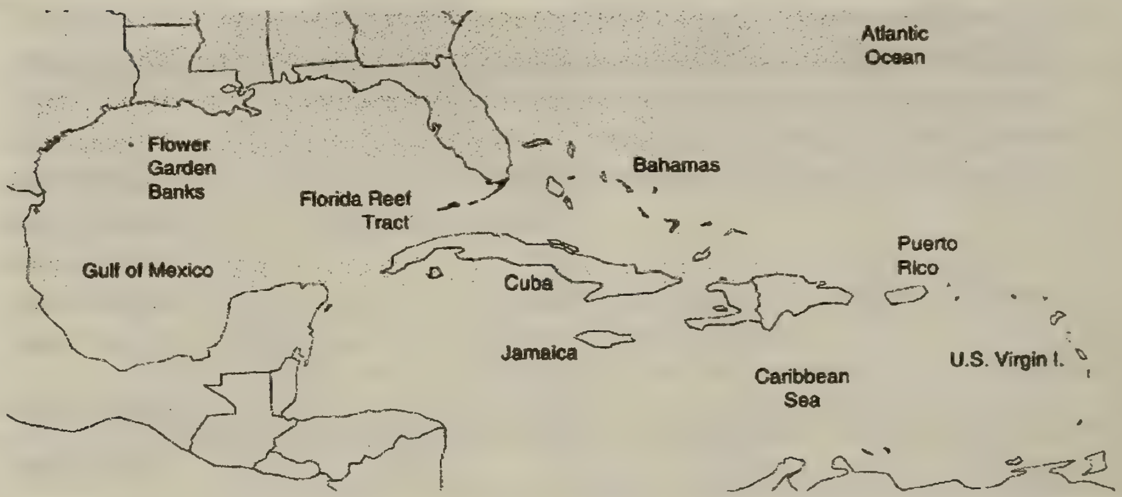
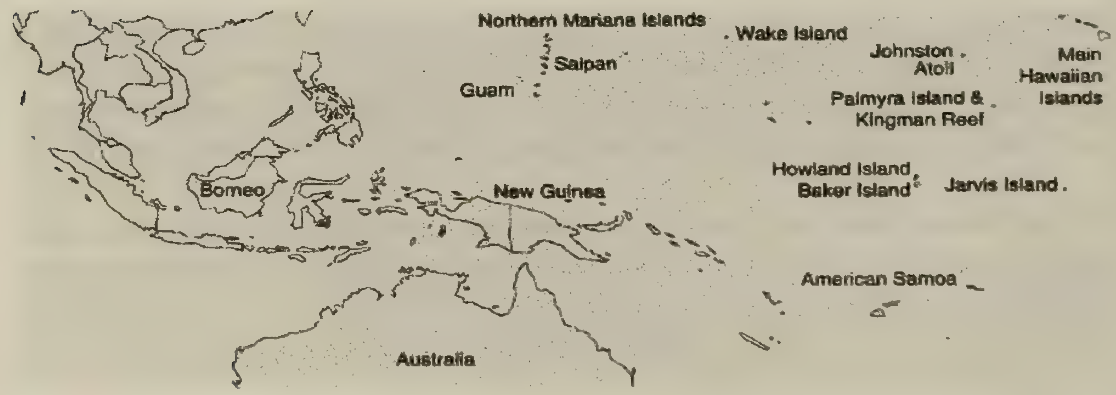


Figure 2. Coral reef ecosystems under United States jurisdiction in the Pacific Ocean are found around: the Northwest and Main Hawaiian Islands; the Line Islands including Palmyra Island, Kingman Reef, Johnston Atoll, Howland Island, Baker Island, and Jarvis Island; American Samoa; Wake Island; and the 14 Mariana Islands including Guam.



WHAT ARE BIOLOGICAL CRITERIA?

Biological criteria are narrative expressions or numerical values that describe the biological integrity of aquatic communities inhabiting waters of a given designated aquatic life use (USEPA 1990a). Numeric biological criteria for fish and invertebrates have been adopted by the state of Ohio to evaluate the relative biological integrity of streams and small rivers. In Maine, narrative biocriteria have been developed for inland waters. Florida and California are in the early stages of developing biocriteria that will include coastal waters.

Biological assessment of water bodies is predicated on our ability to define, measure, and compare the relative biological integrity between similar systems. Biological integrity is the condition of the aquatic community inhabiting unimpaired (or minimally impaired) water bodies of a specified habitat as measured by community structure and function (USEPA 1990a). Community structure and function are the biological measures chosen for bioassessment, consisting primarily of measures of species richness, trophic diversity (relative numbers of herbivores and top carnivores), and indicator species. Unimpaired water bodies form the basis for defining reference conditions for biological criteria. When unimpaired water bodies do not exist within a region, an operational definition of unimpaired can be developed from a combination of minimally impaired coastal waters, historical information, and professional judgment.

Biocriteria measure the relative condition of a given water resource based on the investigation of the health and diversity of its resident biota when compared, in part, to similar reference waterbodies known to be unimpaired or minimally impaired by human activities. Impairment of the water body is judged by its departure from the biocriteria. Biological criteria are, in effect, a practical approach to establishing management goals designed to protect or restore biological integrity. If these criteria are included in state law they can be incorporated in State Water Quality Standards as enforceable regulations over point and nonpoint source discharges.

Below is a simplified diagram outlining the bioassessment process where biocriteria are used as the standard of reference.

Site Monitoring Data
v
converted to
v
Biological Indices
v
compared to
v
Minimally Impaired Reference Site-Supported Biocriteria

An example of a biocriterion would be as follows. A biocriterion for “Class A” coral reef sites off the Florida Keys might be “a benthic index greater than the 25th percentile of least-impaired reference conditions. ” The “Class A” site would be rated impaired if its benthic index fell below the 25th percentile of the “Class A” reference condition. (Note: “Class A” is an arbitrary name used in this example for a particular coral reef habitat type developed during the habitat classification steps (see 1.3.2) in the biocriteria development process.)

The recognition that chemical water quality analyses do not adequately predict or reflect the condition of all aquatic resources has led to the development of measures of biological integrity expressed by biological criteria. Biological surveys, criteria, and assessments complement physical and chemical assessments of water quality by reflecting the cumulative effects of human activities on a water body including the possible causes of these effects. The biological approach is best used for detecting generalized and non-specific impairments to biological integrity, and for assessing the severity of those impairments. Then, chemical and toxicity tests, and more refined habitat assessments, can be used to identify probable causes and their sources, and to suggest corrective measures.

This process is essential to comply with the intent and purpose of the Clean Water Act; its primary objective, stated in Section 101 (a), is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters."

Biocriteria can be developed from reasonable expectations for the locality based on: historical data; reference conditions; empirical models; and the consensus judgement of regional experts. The reference condition component of biocriteria requires minimally impaired reference sites against which the study area may be compared. Minimally impaired sites are not necessarily pristine; they must, however, exhibit minimal influence by man's activities relative to the overall region of study. They should as much as possible approximate ecological integrity, i.e. the condition of an unimpaired ecosystem as measured by combined chemical, physical (including habitat) and biological attributes.

Biological criteria typically include the condition of aquatic communities at designated reference sites as an important component. The conditions of aquatic life found at these sites are used to help detect both the causes and levels of risk to biological integrity at other sites of that type in a region. Reference sites are used to determine an overall reference condition for waters of a certain type within a region. In keeping with the policy of not degrading the resource, the interim reference conditions - like the criteria they help define - are expected to be upgraded with each improvement to the water resource. It is important that biological criteria not be based on data derived from degraded reference sites. In fact, a concerted effort should be made by States and other jurisdictions to preserve the quality of designated reference sites by setting those areas aside in sanctuaries or parks or by inclusion in use protection programs so that continuity of the biocriteria data base can be maintained.

To develop a biocriteria program requires a rigorous and consistent data gathering process. Four increasingly refined levels or "tiers" of data collection and analysis that the resource manager may use in developing a biocriteria program are described below. The tiers are sequential and cumulative in nature and each progressive tier provides more information and greater decision making confidence to the manager than the last, albeit at a greater expense in time, supplies, and manpower. Briefly they are as follows:

Assessment Tiers

Biological surveys of coral reef ecosystems can be implemented in several tiers, ranging from a simple and inexpensive screening to detailed field sampling, analysis, and assessment. Each integrated tier includes both biological and habitat components. Higher tiers require successively more effort and yield more detailed information on specific biotic assemblages and potential stresses on the system. Higher tiers reflect higher quality information and reduced uncertainty in the final assessment *(sensu* Costanza et al. 1992). The tiered approach gives agencies flexibility in planning and implementing biological surveys. A desktop screening and three field survey tiers are described below.

Tier 0 is a desktop screening assessment that consists of compiling documented information for the coral reef ecosystems of concern through a literature search and sending survey questionnaires to local experts. No field observations are made at this assessment level. Desktop screening should precede any of the three subsequent tiers. Its purpose is to support the planning for monitoring and more detailed assessments.

Information to be compiled in Tier 0 includes area and geomorphometric classification; habitat type; watershed land use; population density; NPDES discharges; water quality data (i.e., salinity, temperature, DO, pH, turbidity); biological assemblage data; and water column and bottom characteristics.

Tier 1 is the least complex of the survey approaches. It consists of a one-time visit to sites during a suitable, predetermined index period to collect biological and habitat data using standardized methods. The focus of this tier is on developing screening or survey information. These variables include a rudimentary identification of organisms (i.e., benthos, fish, macrophytes, or phytoplankton), water column characteristics (i.e., salinity, temperature, DO, pH, Secchi depth and/or turbidity, water depth), and bottom characteristics (i.e., grain size, total volatile solids, and sediment toxicity). States may choose some variation of this list depending on regional characteristics and resources. Evaluation of the data collected, as well as historical data for the area, leads to an initial classification of sites and identification of candidate reference sites.

Tier 2 is more complex. A higher level of detail is incorporated into the standardized biological survey methods and multiple visits to the site are made to address temporal variability and seasonality. Another assemblage (epifauna) could be selected in addition to those listed above. Water column nutrient measurements are added to the Tier 1 water column characteristics. More detailed grain size measurements, plus total organic carbon, are added to the bottom characteristics. The data collected in this tier will allow the development of preliminary biocriteria.

Tier 3 is the most rigorous survey tier. It includes multiple site visits to account for seasonal variations in the selected coral reef ecosystem biological assemblages and should incorporate supplemental studies which might be necessary for diagnostic assessment of the potential causes of observed impairments. This tier adds water column pesticides and metals measurements, plus full grain size characterization, and measurement of acid volatile sulfides and sediment contaminants. This tier also allows the resource agency to develop a database sufficient to support resource management activities to reduce the identified impairments and to develop and refine biocriteria.

THE BIOCRITERIA PROCESS

Development of biocriteria depends on the premise that population and condition parameters of coral reef biota (quantified as metrics or indexes which measure attributes of ecological structure and function) provide a sensitive screening tool for assessing the condition of a coral reef ecosystem. Once biocriteria are developed, based in part on minimally-impaired reference conditions, sites are evaluated to determine how well they measure up against the criteria. The greater the discrepancy, the greater the potential impairment of the water resource. The biocriteria should be carefully developed to closely represent the natural biota, provide the sensitivity to identify marginally disturbed sites, protect areas against further degradation and demonstrate the need for restoration of degraded sites. Well-written biocriteria are not set so high that sites that have reached their full potential (i.e., ecological, tourism, productivity, etc.) are considered as failing to meet the criteria, nor so low that unacceptably impaired sites are rated as meeting them. Biocriteria should be: based on sound scientific principles; quantifiable; and written to protect or enhance the designated use of the area. To account for natural variability in a healthy environment, the criterion should be designed to accommodate seasonality and should be defined as a range, often represented graphically as box plots, rather than as a discrete value.

Characteristics Of Effective Biocriteria

Generally, effective well-written biocriteria share the following common characteristics:

- for scientifically sound, cost-effective evaluations;
- protect sensitive biological values;
- protect healthy, natural aquatic communities;
- and strive for protection of chemical, physical, and biological integrity;
- include specific characteristics required for attainment of designated use;
- are clearly written and easily understood;
- adhere to the philosophy and policy of nondegradation of water resource quality; and
- are defensible in a court of law.

The establishment of formal coral reef ecosystem biocriteria warrants careful consideration of planning, management, and regulatory goals and the best attainable condition at a site. Stringent criteria that are unlikely to be achieved serve little purpose. Similarly, biocriteria that support a degraded biological condition defeat the intent of both the biocriteria process and the Clean Water Act. Balanced biocriteria will allow multiple uses to be considered so that any conflicting uses are evaluated at the outset.

Development Of Coral Reef Ecosystem Biocriteria

The use of multiple measures, or metrics, to develop biocriteria is a systematic process involving discrete steps. The process includes the following steps.

Step 1 - Preliminary Classification Of The Coral Reef Ecosystems Under Consideration And The Selection Of Reference Sites

The classification entails the division of the coral reef ecosystems into classes or groups based on physical and geographic characteristics not subject to human perturbation. The intent of classification is to identify the smallest number of classes which, under ideal conditions, would represent comparable biological communities. A set of multiple reference sites are then selected from within each coral reef ecosystem class. The reference sites are those least impaired by human influence and are characteristic of the biological community represented by that particular class. For better statistical power, each class should have a minimum of 5 to 10 reference sites from which the biocriteria are to be developed for that particular class.

Step 2 - Biological Survey

Both the biotic and physical habitat characteristics are surveyed using standardized methods within each coral reef ecosystem classification. To develop the discriminatory power of the metrics within a class, the survey should include both impaired and minimally impaired sites, and should sample two or more biological assemblages (e.g., infauna, fish, epifauna, macrophytes, plankton). Expanding survey tiers (outlined above) offer increasing refinement and complexity of the survey effort from the number of individuals and biological assemblages sampled, to the taxonomic level of identification, the extent of the physical environment sampled, and the number of sample replicates taken. Each tier represents a greater investment of resources over lower tiers, and a greater level of resolution.

Step 3 - Final Classification

The preliminary coral reef ecosystem classification is tested with the biological data to determine whether it consistently reflects the biological communities. If necessary, the classification is revised. Seasonal and spatial variability in biological data are accommodated by using measures of central tendency and variability, and by indexing the sampling period to one or two seasons (index period sampling). Successful classification will result in less variation within a class, leading to more refined characterization of the reference condition and, therefore, to criteria with better resolution for detecting impairment.

Step 4 - Metric Evaluation And Index Development

Potential metrics which have ecological relevance are identified and tested in this step. These measures should reflect biological properties which are shown to be sensitive to environmental impairment such as richness, diversity and dominance indexes, biomass and mean individual size measurements, trophic shifts, health indexes, abundance proportions of taxonomic groups, and the presence or dominance of tolerant (opportunistic) and sensitive species. Metrics are then evaluated for their ability to differentiate between impaired and minimally impaired sites. Values from various scales of measurements are transformed to scores, which are normally incorporated into an index, such as the Chesapeake Bay Estuarine Index of Biotic Integrity (IBI). Metrics may also be used individually as indicators of biological condition in the overall assessment, after they have been reevaluated using the new data set.

Step 5 - Biocriteria Development

Biocriteria are formulated in part from the metrics and index values developed from the population of reference sites for a given coral reef ecosystem class and are adjusted for aquatic life uses. Other elements of biocriteria are historical information, the consensus opinion of objective regional experts, and in some instances, empirical model results. Each class requires a separate reference characterization (hence, separate reference sites) and separate biocriteria. The reference condition element of biocriteria may be based on a single aggregated index or established for several biological metrics. For example, a biocriterion for “Class B” coral reef sites might be "a planktonic index greater than the 50th percentile of least-impaired reference conditions." A "Class B" site would be rated impaired if its planktonic index fell below the 50th percentile of the "Class B” reference condition.

Step 6 - Implementation Of Monitoring And Assessment Program

An operational monitoring and assessment program serves two primary purposes:

- first, it assesses the potentially impaired test sites; and

- secondly, continued monitoring of selected reference sites helps to determine seasonal and annual variability and trends.

Step 7 - Protective And Remedial Management Action

Where problems have been identified through this effort, land use changes, discharge reduction, pollution abatement, and resource use adjustment can be part of the management response, both to improve degraded areas and to protect exceptional minimally impaired sites from future damage.

Step 8 - Continual Monitoring And Periodic Reviews

The biocriteria-biomonitoring effort progressively improves coral reef ecosystem water resources by cycling back through the sequence to refine the classification, biocriteria, and protection or remediation techniques.

In practice, the biocriteria process involves careful planning; selection of appropriate measurements; detailed sampling design; consistent and reliable survey techniques; prudent data assessment; and responsible application of the biocriteria to protect the water resource.

Advantages Of Bioassessment And Biocriteria

Bioassessment is intended to detect sensitive biological responses to pollution and perturbation. Routine coral reef ecosystem water quality monitoring may not detect effects of, for example, chronic low level nutrient enrichment or ephemeral pollution events (e.g., acidic episodes, spills, short-lived toxicants and pesticides, short-term sediment loading). Bioassessment, by monitoring organisms that integrate the effects of environmental changes, can, in time, detect effects of low level contamination and ephemeral events on the biota.

Bioassessment, coupled with coral reef ecosystem habitat assessment, helps identify probable causes of impairment not detected by physical and chemical water quality analyses alone, such as nonpoint source pollution and contamination, erosion, or poor land use practices. The detection of water resource impairment, accomplished by comparing biological assessment results to the biological criteria, leads to more definitive chemical testing and investigations which should reveal the cause of the degradation. This, in turn, should prompt regulatory and other management action to alleviate the problem. Continued biological monitoring, with the data collected compared to the criteria, will determine the relative success of the coral reef ecosystem management efforts.

Program Interdependence

It should be readily evident from the applications described above that physical, chemical, and biological surveys and monitoring (repetitive surveys of the same area) and biological criteria are interrelated in the coral reef ecosystem water resource management process. In this continually cycling process, monitoring provides the information necessary to identify problems and to establish biocriteria for the decision making, management planning, and implementation necessary to respond appropriately. Continued monitoring then reveals the relative success of the effort by comparing the new results to those criteria again. At this point the criteria or the management plan may be positively adjusted as needed and the cycle repeats. Ideally, the habitat quality, water quality and productivity of the monitored coral reef ecosystems improve with each cycle.

Implementing Coral Reef Ecosystem Biological Criteria

Implementing biocriteria requires an established and standardized methodology for coral reef ecosystem biological assessment adjusted to regional or state conditions. Hence, guidance for state and regional development of biocriteria has two elements which would be described in the biological criteria technical guidance documents.

- **Bioassessment Protocols** are methods used to assess the status and trends of coral reef ecosystems. Guidance documents for bioassessment contain suggested methods and protocols for establishing monitoring programs that use biological assessment.

- **Biocriteria Guidance** assists states in establishing biological criteria for coral reef ecosystems. Biocriteria are a series of ambient coral reef resource quality values or statements of condition that relate to the desired biological integrity for that class of coral reef ecosystem. When established they can be used to evaluate similar coral reef ecosystems in that region. Implementation of biocriteria requires use of bioassessment protocols and a state or regional biomonitoring database. The National Program Guidance for biocriteria described issues related to development and implementation (USEPA 1990a). The first biocriteria technical guidance developed was for streams and small rivers (Gibson et al. 1996). It incorporates both biosurvey techniques and biocriteria development methods. This same approach is being followed in similar documents for lakes and reservoirs, rivers, and wetlands, in addition to the latest technical guidance for estuaries and coastal marine waters (Gibson et al. 1997). It is hoped this study will provide a foundation for a similar biocriteria guidance document for coral reef ecosystems.

DOES SUFFICIENT NEED EXIST TO PREPARE A GUIDANCE DOCUMENT ON CORAL REEF ECOSYSTEM BIOCRITERIA?

THE NEED

Sufficient need does exist to prepare a guidance document on coral reef ecosystem biocriteria for the following reasons.

Coral reef ecosystems are sensitive indicators of poor coastal zone management practices because they are the downstream recipients of watershed pollutants. For many coral reef ecosystems, the effective watershed not only includes adjacent terrestrial components but also includes a seaward component via oceanic currents that can carry pollutants from distant sources. One could argue the watershed for the Florida reef tract not only includes the runoff from the State of Florida but also includes pollution, sediments and nutrients from rivers and other sources located in Gulf of Mexico states, the Caribbean and South America. The use of coral reefs for commercial and recreational activities also makes overexploitation (i.e., overfishing) and coastal zone carrying capacity problems (i.e., overdiving - physical reef damage) evident to frequent users.

Of the approximate 600,000+ km2 of coral reefs world-wide, it is estimated that about 10 percent have already been degraded beyond recovery and another 30 percent are likely to decline significantly within the next 20 years (IUCN 1993).

All the coral reef ecosystems under U.S. jurisdiction near large human population centers are experiencing local anthropogenic related stress (e.g., overfishing, eutrophication, sedimentation, physical damage (Jameson et al. 1995a, Jameson 1995b).

Almost all of the reefs off **Florida** are at risk from a range of factors, including runoff of fertilizers and pollutants from farms and coastal development (Burke et al. 1998). South Florida and Florida Keys seagrass beds, including those of Florida Bay and along the reef tract, cover an estimated 5, 500 km2. In 1987 a massive mortality of seagrasses occurred resulting in the loss of over 40 km2 of seagrass beds. Seagrass mortality has persisted at a lower pace since 1990. A combination of ambient conditions that inhibited the sustainability of the seagrass community and the susceptibility to increased organic loadings from domestic wastes in artificial waterways and dead-end canals within the Keys are possible explanations. Little is known concerning the recent mortality of mangroves but there appears to be a rough spatial correlation with adjacent areas of high salinity in Florida Bay. Evidence is growing that freshwater management practices as far north as Lake Okechobee are having serious effects on coral reef health and coral recruitment (Porter 1995). Unfavorably warm conditions during long-lasting summer doldrums have been linked to coral bleaching. Add to this equation the four-fold increase in local human population since 1930, impacts from land use (sedimentation), water pollution (point, nonpoint and external sources - eutrophication, leaching of land-based septic systems), boating, recreational and commercial fishing, and the activities of over 3 million tourists a year and one is faced with a coral reef ecosystem struggling for survival. The impacts of fishing are particularly significant because recreational fishing is the area's primary tourist-related boating activity, and commercial fishing is the fourth largest industry in the region. There are well-documented reports of local declines in coral populations from monitoring, but there is uncertainty about the areal extent of these changes (USDOC 1994).

Due to rapid development over the last 50 years, two-thirds of **Caribbean** reefs are in jeopardy and most are threatened by pollution effluents from adjacent densely populated islands (Burke et al. 1998). Coastal development has had significant environmental impact, through increased turbidity, on the majority of the Caribbean islands. Tourist-related threats include anchoring, littering, trampling, diver damage and over-collection of coral. Both commercial and recreational fishing pressure, as well as destructive fishing techniques, such as fish traps, poison and blast fishing, and spearfishing, have led to significant declines in fish, lobster, and coral populations. Virtually all of the reefs off **Puerto Rico** are threatened and deforestation has led to erosion and increased soil run-off, causing significant siltation of reefs (Burke et al. 1998). This problem is often aggravated by the input of fertilizers, pesticides, and other agricultural pollutants. Mangrove depletion has been prominent in the majority of the Caribbean islands including Puerto Rico, and the **U.S. Virgin Islands**. In the U.S. Virgin Islands most of the reefs are at high risk (Burke et al. 1998). In the Caribbean, less than 10% of total domestic waste receives treatment before disposal and much reaches coastal waters, causing eutrophication and accelerated algal growth. Sewage pollution has been reported from Puerto Rico and the U.S. Virgin Islands. Oil terminals/refineries (and associated construction activities), tanker traffic, and offshore oil reserves adjacent to the reefs are also of concern in the Caribbean and the threat of related pollution is serious in Puerto Rico and U.S. Virgin Islands. Caribbean coral reef ecosystems also have been afflicted with natural damage due to hurricanes and prolonged algal blooms following the Caribbean-wide mass-mortalities of *Diadema antillarum* in 1983. The lack of herbivory, due to the loss of *Diadema* and chronic overfishing, has allowed algae to replace coral in many areas, particularly after the coral has been reduced during recurrent hurricanes (IUCN/UNEP 1988).

Almost half of **Hawaii's** reefs are vulnerable (Burke et al. 1998). All coral reef habitats in the main Hawaiian Islands are overfished in various degrees. Each main island in the chain is characterized by specific but localized anthropogenic induced problems that are geographically unique and most are found where water circulation is restricted. Sedimentation and eutrophication are generally the most serious problems (Grigg 1997).

U.S. coral reef ecosystems in the **Central Pacific** are also feeling anthropogenic impacts. Military testing and training is active on Johnston Atoll and there are severe residual effects from military construction activities at Palmyra and Johnston Atolls and Wake Island. The remote U.S. islands of Palmyra and Kingman are likely subjected to illegal poaching (Maragos 1997). Dahl (1981) and Dahl and Lamberts (1977) found deteriorating conditions in Samoa.

Fish populations have been seriously affected by human fishing pressure in the **Southern Marianas** and exhibit substantial decreases in catch per unit effort, decreases in abundances of fishes, and major shifts in relative abundance with the decrease in species targeted by fishermen. The most insidious effects are decreases in reproductive potential (as much as 95%) for populations of fishes which are still common but which show major decreases in size distribution. Data from permanent transects show that coral communities have withstood effects of increased tourism since the 1970's, but increased rates of sedimentation and overfishing of herbivores may have reduced the rates of coral replenishment (Birkeland 1997).

THE SOCIO-ECONOMIC VALUE OF U.S. CORAL REEF ECOSYSTEMS

Coral reef ecosystems are valuable for many reasons. They provide thousands of U.S. residents with food, tourism revenue, coastal protection and new medications for increasingly drug-resistant diseases - despite being among the least monitored and protected natural habitats in the world.

In 1990 the coral reefs of Florida alone have been estimated to generate about $1.6 billion from recreation uses (USDOC 1994).

For many Caribbean countries, tourism is now the key economic sector, often providing over 50% of GNP, and growing very fast. In 1990, Caribbean tourism earned $8.9 billion and employed over 350,000 people (Jameson et al. 1995a).

In Hawaii, coral reefs are central to a $700 million and growing marine recreation industry. Reef fish, lobsters, and bottom fish generate about $20 million in landings annually and are an important source of food for local and restaurant consumption (Grigg 1997). Diving brings $148.6 million annually to Guam (Birkeland 1997).

As much as 90% of the animal protein consumed on many Pacific Islands comes from marine sources (IUCN 1993).

EPA LEGISLATIVE MANDATES

The U.S. Environmental Protection Agency has several legislative requirements related to coral reef ecosystem protection. These are related to the Clean Water Act and the Florida Keys National Marine Sanctuary (FKNMS) and Protection Act.

Clean Water Act

The Clean Water Act, Section 101, requires federal and state governments to "restore and maintain the chemical, physical, and biological integrity of the nation's waters." Thus, the Act mandates the restoration and maintenance of biological integrity in the Nation's waters. The combination of performing biological assessments and comparing the results with established biological criteria is an efficient approach for evaluating the biological integrity of coral reef ecosystems. Other pertinent sections of the Clean Water Act are Sections 305(b), 301 (h), and 403(c).

305(b) Reporting

States and the USEPA report on the status and progress of water pollution control efforts in 305(b) reports submitted every five years. Inclusion of biological assessment results in these reports will improve the public understanding of the biological health and integrity of water bodies. Many of the better known and widely reported recoveries from pollution have involved the renewal or reappearance of valued species to systems from which they had nearly disappeared, or systems cleaned to the point that people can harvest and consume the fish and shellfish. Examples of such recoveries are the restoration of the lower Potomac River and shellfish beds in Maine. Incorporation of biological integrity in 305(b) reports will ensure the inclusion of a bioassessment endpoint, and will make the reports more accessible and meaningful to many segments of the public.

301(h) And 403(c) Programs

Two other programs within USEPA that specifically rely on biological monitoring data in coastal marine areas are the 301(h) waiver program and the 403(c) ocean discharger program. The 301(h) program allows marine dischargers who meet specific criteria set forth by USEPA to defer secondary treatment if they can show that their discharge does not produce adverse effects on resident biological communities. As part of the modified

NPDES permit received through this waiver program, the dischargers are required to conduct extensive biological monitoring programs designed to detect detrimental effects to those biological communities.

The 403(c) ocean discharge program (also part of the Clean Water Act) requires that all dischargers to marine waters provide an assessment of discharge impact on the biological community in the area of the discharge and on the surrounding biological communities. This program requires extensive biological monitoring for some dischargers. Community bioassessment methods are valuable in this program for trend assessment and, in some cases, refinement into more rigorous and definitive assessments.

Clean Water Action Plan

This plan was developed by the U.S. Department of Agriculture and the U.S. Environmental Protection Agency, in collaboration with other affected Federal agencies (USEPA 1998). This plan considers the restoration and protection of water quality through three major goals: (1) enhanced protection from public health threats posed by water pollution; (2) more effective control of polluted runoff; and (3) promotion of water quality protection on a watershed basis. This plan will build upon existing frameworks such as the Clean Water Act sections, 305(b), 303(d), and 319. The watershed approach to management allows for a more efficient implementation of point and non-point source controls and are intended to enhance the protection of sensitive natural areas such as coastal ecosystems.

Florida Keys National Marine Sanctuary Requirements

Recognizing the critical role of water quality in maintaining sanctuary resources, Congress directed the U.S. Environmental Protection Agency and the State of Florida, represented by the Florida Department of Environmental Protection, to develop a Water Quality Protection Program for the sanctuary. This is the first such program ever developed for a marine sanctuary.

The purpose of the Water Quality Protection program is to recommend priority corrective actions and compliance schedules addressing point and nonpoint sources of pollution to restore and maintain the chemical, physical, and biological integrity of the sanctuary. This includes restoration and maintenance of a balanced, indigenous population of corals, shellfish, fish and wildlife, and recreational activities in and on the water.

In addition to corrective actions, the 1990 Florida Keys National Marine Sanctuary and Protection Act (Public Law 101-605) also requires development of a water quality monitoring program and provision of opportunities for public participation in all aspects of developing and implementing the program.

THE MANAGEMENT NEED

The biocriteria-bioassessment process, as outlined in 1.3, helps coral reef ecosystem managers identify impairment of sites designated by the government for special uses (i.e., national marine sanctuary, harbor, etc.). It expands and improves designated beneficial use classifications and their associated water quality standards. It detects problems other survey methods may miss or underestimate. It is a process which helps the resource manager set program priorities. And it can be used to evaluate management and regulatory efforts.

Identifying Impairment Of Special Designated Use Sites

By comparing monitoring data to established biocriteria, the impairment of designated special use sites - such as national marine sanctuaries with coral reef resources - can be evaluated.

Expansion And Improvement Of Water Quality Standards

When EPA and a State elect to incorporate biological criteria in their designated use water quality standards (i.e., for the Florida Keys National Marine Sanctuary), these criteria serve not only to refine those standards, they become benchmarks for decision making as well as elements for regulatory decisions when the standards are enforced.

Detection Of Problems Other Methods May Miss Or Underestimate

Coral reefs are efficient recyclers. As a result, chemical pollutants (i.e., nitrates and phosphates in a eutrophication situation) are taken up by the system at extremely rapid rates. In many cases, water sampling can not detect a significant change in water quality whereas detrimental changes could be detected using biocriteria that included bioindicator species.

Also, in the process of establishing biocriteria, more data and information is inevitably recorded than was previously available. The review of this new information often reveals problems not evident before or provides expanded insight into existing concerns and issues. With this information, the coral reef ecosystem resource manager is often able to view his responsibilities from a new and expanded perspective.

Helping The Water Resource Manager Set Priorities

In light of the new information described above, the schedule of activities, allocation of funds, and uses of personnel and equipment may be more appropriately prioritized according to the urgency or magnitude of the problems identified.

With the expanded available biological information augmenting chemical and physical information, managers can apply a triage approach to water resource projects based on the actual condition of the coral reef affected. This is much like a physician evaluating multiple emergency medical patients. Essentially, areas that are critically impaired, those that are moderately impaired, and those in good condition for which protection rather than remediation is required, can all be identified. Rational decisions can then be made about how to apply limited resources for the best results.

Use Of Bioassessment And Biocriteria To Evaluate The Success Or Failure Of Coral Reef Ecosystem Management Initiatives Or Regulations

A coral reef manager may design a biosurvey to collect data before and after a permit, regulation or other management effort has been implemented, perhaps augmented by spatially distributed nearfield/farfield sampling as well. With this information and the biocriteria decision-making benchmark, it is possible to clearly evaluate the environmental response of the system to the methods applied. This process is particularly appropriate to the National Pollution Discharge Elimination System (NPDES) permit review procedure. It is not necessary or advisable at this time that biocriteria be incorporated in NPDES permits. But biomonitoring above and below a permit site when compared to the established biocriteria will reveal the adequacy of the permit to achieve its intended purpose. If the coral reef biota are unimpaired or recovering, it may be wise to leave the permit, management practice or regulation as is. If the coral reef biota are impaired or declining, the review recommendation may be to change the permit, management technique or regulation accordingly. With NPDES permits, the five year review cycle - especially if permit reviews are on a staggered, rotating basis - allows sufficient time for extensive biological information to be developed so this determination can be made with reasonable confidence.

PROGRAMMATIC NEEDS

EPA Ecological Risk Assessment Program Benefits

Increased interest in ecological issues such as global warming, habitat loss, acid deposition, reduced biological diversity, and the ecological impacts of pesticides and toxic chemicals prompted EPA to establish the Ecological Risks Assessment Program. EPA's Framework for Ecological Risk Assessment (USEPA 1992) and Guidelines (USEPA 1998) offers starting principles and a simple structure as guidance for current ecological risk assessments and as a foundation for future EPA proposals for risk assessment guidelines. Biocriteria can provide a firm biological foundation for ecological risk assessment.

U.S. National Marine Sanctuary Designation Priorities

Historically, designation of national marine sanctuaries has been to a large degree threat-driven. All sanctuaries to date have been designated because they are in danger of being irrevocably damaged due to human impacts. The need for reference sites as part of a national coral reef ecosystem biocriteria program would clearly establish the necessity for protecting remote and in many cases unthreatened sites as national marine sanctuaries. Identifying reference sites for a coral reef ecosystem biocriteria program will help national marine sanctuary leaders focus on these areas for future sanctuary designations.

U.S. And International Coral Reef Ecosystem Monitoring Programs

A coral reef ecosystem biocriteria program with associated reference sites would provide a focal point and standard framework for monitoring efforts in U.S. National Marine Sanctuaries and for researchers working on U.S. coral reef ecosystems not under the sanctuary umbrella. This biocriteria program framework could also be transferred to other nations with coral reef ecosystem management responsibilities.

In addition, biocriteria, indices and monitoring data would be of great value to the recently established Global Coral Reef Monitoring Network (GCRMN) and could be used as a yardstick for NGO and volunteer monitoring programs, such as Reef Check, to compare their data against.

Using standard biocriteria for evaluating the condition of U.S and other coral reef ecosystems will also provide more realistic and reliable regional and global perspectives on coral reef resource status and trends.

DOES SUFFICIENT INFORMATION EXIST TO DRAFT BIOCRITERIA GUIDANCE?

ROLE OF THE 1997 EPA ESTUARINE & COASTAL MARINE WATERS BIOASSESSMENT & BIOCRITERIA TECHNICAL GUIDANCE

While a separate guidance document will be needed for the U.S. Coral Reef Ecosystem Biocriteria Program, the 1997 USEPA Draft Estuarine & Coastal Marine Waters Bioassessment & Biocriteria Technical Guidance (Gibson et al. 1997) provides a useful framework to design the U.S. Coral Reef Ecosystem Biocriteria Program around.

DIVERSITY OF BIOINDICATORS

Traditionally, bioindicators have referred to indicators using non-human organisms. However, with the growing realization that man is the root cause of many problems in the coastal zone and in coral reef ecosystems (Jameson et al. 1995a), bioindicators that are more anthropogenic-focused are also discussed in this report's consideration of potential indicators for a U.S. Coral Reef Ecosystem Biocriteria Program.

EXISTING U.S. PROGRAMS RELEVANT TO CORAL REEF ECOSYSTEM BIOASSESSMENT AND BIOCRITERIA DEVELOPMENT

Sustainable monitoring programs are critical for a successful biocriteria program. Unfortunately, the cost of coral reef ecosystem monitoring is expensive and government and private budget support has historically been inconsistent (Jameson et al. 1995a).

There are only 4 examples of long-term (greater than 5 years in duration) coral reef ecosystem monitoring programs in U.S. waters that are still ongoing today (Table 2). All of these programs except CARICOMP - Puerto Rico are government funded. The other 5 notable long-term efforts (Table 3) have been intermittent in their sampling timing and for the most part are privately funded (Ginsburg 1994).

Many short-term or project-specific monitoring efforts have been conducted by universities, students, and marine laboratories, but repeating these is, in many cases, dependent on the cooperation of the personnel who conducted the original work. Data from these short-term monitoring efforts (less than 5 years in duration) could be useful building blocks for a U.S. biocriteria program and the potential of each of these efforts should be evaluated.

Table 2: Summary of past and existing long-term (greater than 5 years) monitoring programs relevant to coral reef ecosystems under U. S. jurisdiction.

Program	Location	Period	Status	Parameters	Contact
Flower Gardens National Marine Sanctuary Monitoring Program	Gulf Of Mexico	1972-present	**Ongoing**	Photo techniques and direct measurements of coral cover, population levels, diversity, evenness, accretionary - encrusting growth	Steve Gittings 301-713-3145
Virgin Islands National Park	U.S. Virgin Islands - St. John	1989-present	**Ongoing**	Coral & macroalgae cover, coral physical damage, disease & fish catch	Caroline Rogers 809-693-8950
CARICOMP	Puerto Rico	1993-present	**Ongoing**	CARICOMP Level 1	Jorge Garcia 809-899-2048
NOAA Mussel Watch Program	Florida Keys (6 sites), Hawaii (4 sites)	1986-present	**Ongoing**	Trace metals and organic compounds	Gunnar Lauenstein 301-713-3028 X152
NOAA Status & Trends - Benthic Surveillance	Florida Keys & vicinity - some cruises with EPA/EMAP	1984-1994	Stopped	Sediment samples, fish chemistry, fish biology	Bernie Gottholm 301-713-3034 X168
Dry Tortugas National Park Coral Reef Monitoring	Florida - Dry Tortugas (3 sites)	1989-1995	Stopped	Quadrate sampling of stony & soft coral spp. abundance, diversity & evenness	Walter Jaap 813-896-8626

Table 3: Summary of notable existing intermittent long-term (greater than 5 years) monitoring programs on coral reef ecosystems under U. S. jurisdiction.

Program	Location	Period	Status	Parameters	Contact
Harbor Branch - Carysfort Reef	Florida	1974-1982	Intermittent	Coral cover, diversity, recruitment, & mortality	John Halas 305-451-7717
The History of *A. palmata*	Florida - Dry Tortugas	1881-1993	Intermittent	Distribution & abundance	Walter Jaap 813-896-8626
University of Georgia - Institute of Ecology	Florida - Looe Key (2 sites), Key Largo (2 sites), Biscayne National Park (2 sites)	1984-1991	Intermittent	Photo stations monitoring species number, % cover, & species diversity for scleractinia & hydrozoan corals	James Porter 706-542-3410
Kaneohe Bay	Hawaii - Kaneohe Bay	1970-1990	Intermittent	Changes in coral & algal cover, changes in coral spp. diversity	Cynthia Hunter 808-956-3946
University of Guam technical reports, theses, publications	Marianas Islands - various locations	Starting in late 1960's	Intermittent	Coral cover & recruitment, sedimentation, fish catch	Charles Birkeland 671-735-2184

1996 EPA Water Quality Protection Program For The Florida Keys National Marine Sanctuary

The 1996 EPA Water Quality Protection Program for the FKNMS (FKNMS-WQPP) is a new initiative (USEPA 1996) that could provide the basis for a biocriteria program in the Florida Keys, if funding remains sustainable. Table 4 summarizes the different facets of this program.

Table 4: Florida Keys National Marine Sanctuary Water Quality Protection Program .

Program	Location	Period	Status	Parameters	Contact
Coral reef & hard bottom monitoring	Florida Keys National Marine Sanctuary (40 sites)	1996-present	On-going	Video sampling to determine net reef changes in% cover, stony coral spp richness, net changes in reef community parameters, changes in reefs compared to entire ecosys, & changes linked to specific regions of land	Florida Marine Research Institute - Jennifer Wheaton 813-896-8626
Water quality monitoring	Florida Keys National Marine Sanctuary (150 sites)	1996-present (Quarterly monitoring)	On-going	Dissolved nutrients, chl a, APA, ppt, temp, DO, NTU and k	Florida Intl. University - Ronald Jones 305-348-3095
Seagrass monitoring	Florida Keys National Marine Sanctuary (300+ sites)	1996-present	On-going	Distribution/ abundance, demographics, productivity of dominant species, nutrient availability	Florida Intl. University - Jim Fourqurean 305-348-4084
Data management	Florida Keys National Marine Sanctuary	1996-present	On-going	Design data management plan & system and implement system	Florida Marine Institute - Chris Friel 813-896-8626

1996 EPA Water Quality Special Studies Program For The Florida Keys National Marine Sanctuary

The objective of the Special Studies Program is to identify and understand cause and effect relationships among pollutants, transport pathways, and the biological communities of the sanctuary (USEPA 1996). The results of the studies outlined in Table 5 will be important in developing biological criteria for coral reef ecosystems in the FKNMS.

Table 5: Florida Keys National Marine Sanctuary Water Quality Protection Program Special Studies.

Program	Location	Period	Status	Parameters	Contact
Semi-synoptic sampling of phytoplankton to locate nutrient inputs	FKNMS	1995-present	On-going	Phytoplankton abundance (chlorophyll) after large rains	University of Miami - Larry Brand 305-361-4600
Use of natural & artificial tracers to detect subsurface flow of contaminated ground-water	FKNMS	1995-present	On-going	Measures Rn, CH4, N to locate ground-water seeps. Injects SF6 and I into cess-pools, septic tanks, disposal wells to assess linkage to sewage disposal and measure flow rate	Florida State University - Jeffrey Chanton 805-644-7493
Symbiotic algae as indicators of nutrient exposure	FKNMS	1995-present	On-going	Ammonium enhancement of dark carbon fixation by algae, methyla-mine uptake by algae, free am-ino acid content of algae & corals, CNP ratio of algae & coral tissue, coral growth rates	Harbor Branch Oceanographic Institution, Clayton Cook 407-465-2400

Table 5 continued: Florida Keys National Marine Sanctuary Water Quality Protection Program Special Studies.

Program	Location	Period	Status	Parameters	Contact
Algal tissue nutrients as indicators of nutrient enrichment	FKNMS	1995-present	On-going	Determine temporal and spatial variation relative to sources of wastewater pollutants of tissue CNP of macro-algae & sea-grass epiphyt-es, identify hot-spots, select indicator spp.	Harbor Branch Oceanographic Institution, Dennis Hanisak 407-465-2400
Waste-water nutrients in ground waters: contrasting behaviors of phosphorous & nitrogen	FKNMS	1995-present	On-going	Installs monitoring wells of varying depths surrounding injection wells to assess potential for transport of anthropogenic nutrients from sites of injection to zones of ecological sensitivity	Pennsylvania State University, Lee Kump 814-865-4700
High freq. monitoring of waste-water nutrient discharges and their ecological effects	FKNMS	1995-present	On-going	Use biomass, tissue CNP ratios, alkaline phosphatase activity & 14N/15N ratios to monitor effects of wastewater nutrient inputs	Harbor Branch Oceanographic Institution, Brian Lapointe 407-465-2400
Ground-water seepage demonstration project	FKNMS	1995-present	On-going	Construct clean enclosure around ground-water seep with check valve and evaluate effect of enclosure against control site (no seep)	U.S. Geological Survey, Eugene Shinn 813-893-3100

Table 5 continued: Florida Keys National Marine Sanctuary Water Quality Protection Program Special Studies.

Program	Location	Period	Status	Parameters	Contact
Hawk Channel transport study	FKNMS	1995-present	On-going	Quantify volume transport over seasonal and annual time scales through selected passes and document storms, determine flow patterns in Hawk Channel, identify mechanisms that exchange water between Hawk Channel and the Florida Straits, determine wind driven exchanges, determine advection and diffusion processes in transporting Florida Bay water across Hawk Channel	Harbor Branch Oceanographic Institution, Ned Smith 407-465-2400

Other New Monitoring Initiatives In The Florida Keys National Marine Sanctuary

Table 6 lists several new monitoring initiatives that could provide valuable long-term baseline data to the U.S. Coral Reef Ecosystem Biocriteria Program.

Table 6: Other new monitoring initiatives in the Florida Keys National Marine Sanctuary.

Program	Location	Period	Status	Parameters	Contact
CARICOMP - Florida Keys	To be determined	Starts in 1998	On-going	CARICOMP Level 1	Florida Institute of Oceanography John Ogden 813-553-1100
FIO Benthic Monitoring	No-take zones in the FKNMS	5 year contract with NOAA	On-going	TV techniques and coral recruitment studies using precision photography	Florida Institute of Oceanography John Ogden 813-553-1100
NOAA/EPA Dry Tortugas Baseline Data Program	Dry Tortugas National Park	1997-2002	On-going	Biological inventory & habitat mapping for ecological reserve characterization	NOAA, Michael Crosby 202-482-2977
EPA Disease Studies	Dry Tortugas to Key West	1996-2001	On-going	Distribution & abundance of disease, monitoring of water quality, analysis of infected coral samples	EPA Ocean & Coastal Protection Division - Ken Potts 202-260-7893

Florida Assessment Of Coastal Trends (FACT)

FACT is the nation's first coastal environmental indicator system. First initiated in 1995 by the Florida Coastal Management Program via contract to the Florida Center for Public Management, FACT 1997 (Bergquist et al. 1997) updates data in the indicators, deletes indicators with poor or nonexistent data sources, adds new indicators to improve the system and reformats the individual indicator sheets to improve their graphic effect.

The coral reef ecosystem component of FACT 1997 includes the EPA coral reef/hard bottom monitoring program (USEPA 1996) coordinated by Jennifer Wheaton of the Florida Marine Research Institute (Table 3.3).

State Of Florida Environmental Indicator Technical Assistance Series

The 1996 State of Florida Environmental Indicator Technical Assistance Series is terrestrial oriented. However, some indicators (i.e., water quality, air pollutants, climate change, ozone depletion, atmospheric deposition, pesticides, accidental releases, ecosystems land use/land cover, use and management of natural resources) in this series warrant further investigation as components of a Florida Keys focused coral reef ecosystem biocriteria program.

Likewise, certain aspects of the U.S. Coral Reef Ecosystem Biocriteria Program may also be beneficial to this indicator program.

International Umbrella Programs

Two international umbrella monitoring programs that are relevant to a U.S. Coral Reef Ecosystem Biocriteria Program include:

- The Global Coral Reef Monitoring Network (GCRMN). The GCRMN database would benefit from the U.S. Coral Reef Ecosystem Biocriteria Program bioassessment data and would be very interested in any indices developed as part of the biocriteria program.

- The Caribbean Coastal Marine Productivity Program (CARICOMP). CARICOMP Puerto Rico could provide data to the U.S. Coral Reef Ecosystem Biocriteria Program and would also benefit from new indices developed as part of the biocriteria program.

REVIEW OF POTENTIAL CORAL REEF ECOSYSTEM BIOINDICATORS FOR BIOASSESSMENT AND BIOCRITERIA DEVELOPMENT

Indicator organisms have a long history of use for detecting qualities about an environment that are otherwise difficult to perceive, from the well-known "canary in the coal mine" to the highly successful "Musselwatch" program in North American bays (Soule 1988). Freshwater and marine organisms have been used extensively as bioindicators since the 1970's (Phillips 1980).

The use of bioindicators has been justified in marine pollution monitoring programs for at least three reasons (Maher and Norris 1990).

- First, they assess only those pollutants which are bioavailable, ostensibly those which are most important.

- Secondly, they can reveal biological effects at contaminant levels below current chemical analytical detection limits (either due to chronic, low level pollution or short-term pulses).

- Finally, bioindicators can help assess synergistic or additive antagonistic relationships among pollutants, an important consideration with the typical combination of pollution impacts impinging on most reefs in the developing world (Ginsburg 1994).

Bioindicators can be classified into several main groups, including in-situ pollution indicators (Kovacs 1992, Root 1990), transplanted or naturally-occurring bioaccumulating indicators (de Kock and Kramer 1994), indicators used in laboratory toxicity-testing (Cairns and Pratt 1989, Kimball and Levin 1985), and most recently, biodiversity bioindicators (Noss 1990, Pearson 1994). Of these major groups, bioindicators have been used most effectively and extensively for in-situ freshwater and temperate marine pollution monitoring (e.g., Lenat 1980, Lenat et al. 1988, Soule and Kleppel 1988, Faith 1990 and Rosenberg and Resh 1993). Though coral reef bioindicator systems are not as well developed as those for freshwater and temperate marine habitats, the majority of those proposed are also in-situ pollution/stress indicators. As such, this review shall focus primarily upon this type of bioassessment.

Continuing development of freshwater and marine bioassessment protocols over the past three decades has led to the recognition of a number of important criteria for selection of indicator organisms (e.g., Phillips 1980, Soule 1988, Wenner 1988, Kovacs 1992, Jones and Kaly 1996). Most workers agree that the indicator organism(s) should be abundant throughout the monitoring area and easy to sample in an objective, quantitative manner.

Indicators should not be subject to direct human exploitation, which would obviously confound any trends in monitoring their abundance or other population parameters. Additionally, it is highly advantageous if the organism(s) have a stable taxonomy which is easily taught to non-specialists; Cranston (1990) makes a strong case for the importance of identification to the species level in all bioassessment programs (though see Warwick (1988) for a different view).

Perhaps most importantly, bioindicators should provide an early warning of sublethal stresses to the primary habitat-structuring organisms (scleractinian corals, in the case of coral reefs), in order that management actions can be taken before the reefs begin serious decline. Brown (1988) and Jones and Kaly (1996) have further argued that coral reef bioassessment should focus on monitoring hard corals directly, as these are the most "important" organisms on the reef. While this view certainly has merit, it seems reasonable that indicator species which respond to the same stressors as the corals, but in a more sensitive manner, should also provide a useful early warning of deteriorating conditions on a reef.

A related criteria holds that the organism should reveal gradations in response relative to the level of stress (e.g., level of pollution). Similarly, Noss (1990) suggests that indicators should be capable of providing a continuous assessment of stress over a wide range of stress (i.e., euryoecious species). This criterion has been disputed in the literature by those who suggest that sensitive species with narrow environmental tolerances (stenoecious species) are more suitable as bioindicators (e.g., Lang et al. 1989). Certainly, a case can be made in favor of either viewpoint, depending on the objectives of the monitoring program. Nonetheless, as a general rule, the absence of a sensitive organism in a monitoring situation is much less informative than reduced abundance or other graded responses (Podani 1992). At best, the simple presence or absence of a sensitive species provides information on whether certain threshold conditions have been surpassed; whereas a graded response in abundance or some other organismal parameter can provide more detailed information on the level of ecosystem stress (e.g., extent of eutrophication).

Similarly, Erdmann and Caldwell (1997) suggest that a useful bioindicator should show a response which is indicative of a relatively small number of anthropogenic stressors (i.e., response specificity). Brown (1988) provides a contrary opinion, suggesting that a generalized response to a wide range of environmental stressors (such as zooxanthellae loss in corals) is preferable for bioassays. However, such a generalized response would seem to contradict a primary objective of using bioindicators (*viz.* to provide an early warning of sublethal stresses in order that management actions can be taken to ameliorate this stress). As Wells (1995) points out, "if the cause of a change on a reef is not known, finding the correct management solution is difficult." With this in mind, response specificity would seem an important criteria in selecting coral reef bioindicators.

Jones and Kaly (1996) discuss three further bioindicator criteria which have been vigorously debated in the literature; these involve the characteristics of mobility and longevity of the indicators, as well as the cosmopolitan nature of the indicator. A number of workers (e.g., Bilyard 1987, Alcolado et al. 1994) have suggested that sessile or sedentary organisms are an obvious first choice for biomonitoring, as these organisms are continuously exposed to local environmental conditions. Reese and coworkers (Reese 1981, Hourigan et al. 1988) have argued that to the contrary, mobile species are preferable in biomonitoring, as they can simply move when environmental conditions begin to deteriorate - thus providing an early warning of stress. Though the majority of biomonitoring programs in practice today seem to focus on benthic, sessile or sedentary organisms (see Spies 1984 for further theoretical backing), both viewpoints are easily supported, and the characteristic of mobility appears to have little value as an absolute standard for choosing a bioindicator. Similarly, the value of cosmopolitan indicators, though often championed by proponents of standardized, widespread bioassays such as the Musselwatch program (Goldberg et al. 1978), is debatable. As Jones and Kaly (1996) point out, organisms with extremely limited ranges are ostensibly most at risk of extinction, and therefore likely candidates for monitoring.

A final organismal characteristic with strong proponents in favor of either extreme is organismal longevity. Hourigan et al. (1988) and Crosby and Reese (1996) suggest that long-lived organisms which tolerate low-level, chronic stresses for long periods of time will be able to provide an integrated signal of this stress which species with short generation times might not. They also point out that it is often easier to detect changes in populations of longer-lived species. At the other extreme, species with short generation times often respond very quickly to environmental changes (Jones and Kaly 1996), which suggests that they may be a more sensitive choice of bioindicator. Furthermore, as Brown (1988) points out, it is generally the juveniles and new recruits of a particular organism which are the most sensitive to environmental stress, especially water quality deterioration. Numerous studies support the concept that larval settlement and recruitment are often the ecological processes most affected by marine pollution, rendering the consideration of species longevity irrelevant (Gajbhiye et al. 1987, Hernnkind et al. 1988, Jackson et al. 1989, Erdmann and Caldwell 1997). Clearly, all three of the aforementioned criteria are highly debateable and have limited value as absolute standards for selection of bioindicators. Rather, the application of these indicators will depend on the particular monitoring questions being asked.

The universal importance of considering recruitment issues in designing marine bioassessment programs is rarely debated, however. For bioassays which will measure species abundance, for example, it is highly preferable to choose organisms which demonstrate recruitment which is independent of the organism's population size at any given site, in order to avoid autocorrelation in abundance measures over time (Garrity and Levings 1990). Likewise, it may be preferable to select organisms which are not normally subject to natural, drastic fluctuations in recruitment, as this would also confound interpretations of species abundance measures. This problem is somewhat ameliorated by selecting species which demonstrate multiple recruitment periods per year. Not only would this prevent a single, naturally poor recruitment period from dominating abundance measures for long periods of monitoring, but it would also provide multiple opportunities to detect negative impacts of low-level, intermittent stress on new recruits. Such criteria are obviously more germaine to bioassessment programs which involve frequent sampling during the course of a year.

Despite the above precautions, however, a potential problem with using indicator species to monitor coral reefs is that natural fluctuations are inherent to such complex systems, and hence monitoring abundance of a particular taxa may be inconclusive or misleading (Spellerberg 1991). This problem is partly alleviated by monitoring multi-species assemblages, as similar population responses in a number of different taxa should help reduce "noise" associated with natural fluctuations in abundance of a given species (Soule 1988). However, Brown (1988) and Wenner (1988) further suggest that simply monitoring abundance and diversity measures can be insensitive. Osenberg et al. (1994) point out that monitoring individual-based parameters such as growth rate and fecundity measures can reveal sublethal differences between populations that abundance and diversity measures alone might miss. Biomonitoring programs which include such measures should obviously choose indicator organisms which have readily ascertainable (and measurable) growth, reproduction, and recruitment.

Finally, Risk et al. (1995) and Erdmann and Caldwell (1997) discuss several further criteria which are specific to bioassessment programs designed for use in local, community-based coral reef management projects (such as those in many developing countries). Those authors suggest that bioassays for these programs should be inexpensive, require a low-capital equipment investment (i.e., the use of SCUBA may be inappropriate), and should be easily taught to local participants with at most a high-school science background.

Obviously, the above discussion of bioindicator selection is provided as a general guide; there is no one "perfect" bioindicator (Cairns 1986), and not every characteristic discussed is applicable to every proposed bioassessment. Jones and Kaly (1996) warn against a "shopping list" approach to selecting bioindicator organisms. Rather, selection of the most appropriate bioindicators for a particular biomonitoring program depends upon the monitoring question(s) being investigated, as well as the specific monitoring situation expected (including regional, financial, level-of-expertise, and time considerations). As the science of coral reef management develops, there is an increasing awareness that management objectives and methods will vary significantly between regions and countries, contingent upon the status and use of reefs in those areas (Done 1995, Wells 1995). Clearly, bioassessment protocols should reflect this diversity of management objectives, and need to be specifically tailored to meet each monitoring program's needs and capabilities.

The bioindicators discussed below are summarized in table format in Appendices 1 - 5, with additional notes on biogeographic location and season, following the categories used in: *Draft Estuarine & Coastal Marine Waters Bioassessment & Biocriteria Technical Guidance* (Gibson et al. 1997).

Scleractinian Coral Bioindicators

Coral reef monitoring programs have become ubiquitous over the course of the past two decades (Risk 1992, Eakin et al. 1997), ranging from monitoring by individual research scientists to that conducted by large institutions like the Australian Institute of Marine Science or the CARICOMP (Caribbean Coastal Marine Productivity) network. The scope of reef monitoring has recently expanded even further with the introduction of monitoring programs specifically designed for volunteer sport divers, such as the ReefBase Aquanaut and Reef Check programs (McManus et al. 1997, Hodgson 1997).

Percentage hard coral cover, diversity indices, and vitality indices

To date, the majority of coral reef monitoring programs have focused on two primary parameters:

1. Percentage of live hard coral cover and;
2. Various indices of the diversity of benthic cover, either at the species or life-form level (Dodge et al. 1982, DeVantier 1986, Gomez and Yap 1988, Aronson et al. 1994, English et al. 1994).

Many workers have discussed the dangers of relying too heavily on these two state variables (e.g., Dustan and Hallas 1987, McLanahan 1997), and some have even questioned their significance. For example, Brown (1988) describes several studies which measured no effect of severe environmental perturbations on coral community diversity indices (though at least one comprehensive study, that of Tomascik and Sander 1987a, did demonstrate a sensitive response of species diversity to eutrophication stress).

Research recommendation: In general, these two parameters are now considered to be important to measure, but insufficient as the sole data used in reef assessment (McLanahan 1997). The realization that 100% live hard coral cover is not a standard to which most coral reefs can compare, even in a pristine state, has led a number of workers to suggest the use of coral "vitality" or "mortality" indices which take into account ratios of live and dead coral cover in an estimation of reef "health" (Grigg and Dollar 1990, Dustan 1994, Gomez et al. 1994, Ginsburg et al. 1996, Steneck et al. 1997). Similarly, Aronson et al. (1994) suggest the measurement of reef topographic complexity as a more relevant indicator of reef health than simple percentage live cover. Despite the potential improvements of these methods over measurement of percentage cover and diversity only, and their utility in providing an assessment of reef "health", neither provide an early warning function of deteriorating environmental conditions. Standardized monitoring procedures quantifying coral abundance and diversity are snapshots in time, and are non-predictive. In many cases, impact studies (e.g. sewer outfalls) have been started years after the insult began. In such a case, we must assume that sensitive species have already been eliminated, and that we have reached a stable state. By carefully choosing sensitive scleractinian coral indicator species and transplanting them back to affected areas (over a gradient) we can choose several sub-lethal indicators (possibly growth rate, fecundity, etc) and determine at what distance these are no longer affected. We can then determine if reaching that level of water/substratum quality is cost effective or possible considering the improved conditions for reef recovery.

Brown (1988) reviews a number of additional coral-focused parameters which may provide an indication of sublethal environmental stress and therefore be of particular use in pollution assessment studies. These include:

- measurement of coral growth (skeletal extension) rates;
- calcification and productivity profiles;
- coral fecundity and recruitment;
- monitoring for zooxanthellae loss, coral diseases and cyanobacterial blooms; and
- measurement of the bioaccumulation function of coral skeletons.

Each of these is briefly reviewed below in the context of the bioindicator criteria presented above.

Growth rate

A number of studies have suggested that coral growth rate is one of the most relevant individual-based parameters for measuring declining environmental quality on reefs (reviewed in Brown and Howard 1985). Despite this assertion, the literature provides conflicting evidence of the effects of stress on coral skeletal extension rates. For example, though a number of workers (e.g., Hudson 1981, Cortes and Risk 1985, Rogers 1990) have suggested that massive corals demonstrate a decrease in growth rate under environmental stress such as increased siltation, Brown et al. (1990) found no apparent effect of increased sedimentation on growth rates of *Porites* on a reef in Thailand which had experienced significant coral mortality due to dredging. Still others (Tomascik and Sander 1985, Risk et al. 1995) report that corals from eutrophied and sedimented sites often demonstrate an initial *increase* in growth rate due to increased nutrient availability and the use of particulate matter as a food source (though corals on the most eutrophied sites in these studies did show a reduction in growth rates). Edinger (1991) has termed this the "Janus effect", whereby nutrient enhancement can increase coral growth rates up to a certain critical level, after which eutrophication becomes deleterious and growth rates decline.

Research recommendation: Obviously, this phenomena is in need of further research before coral growth rates can be interpreted reliably and their measurement properly calibrated for use in water quality assessment.

Productivity and calcification profiles

Brown (1988) also suggests using productivity and calcification profiles as a means of classifying the status of coral reefs. This bioassay is based upon the concept that healthy reefs operate within narrowly-defined metabolic limits, such that a profile of a reef's performance with respect to these limits should provide an assessment of its current status (Barnes 1983). Theory and data show it is possible to measure productivity and calcification from changes in the oxygen concentration and pH of sea water flowing across a reef flat. When more is known about the variations in the respiratory and metabolic quotients of coral reef benthic communities, it should be possible to characterize the metabolic performance of large areas of reef flat by means of a few transects in the day and at night (Barnes 1983).

Chalker et al. (1985) developed a respirometer that can be deployed in situ on coral reefs to a depth of 50 meters for the measurement of primary productivity and calcification by corals, calcareous algae and the communities living on dead scleractinian skeletons using the technique developed by Barnes (1983).

McLanahan (1997) further advocates that the calcium carbonate balance (ratio of carbonate accretion to carbonate erosion) is the "universal currency of reef health and value".

Research recommendation: Though the techniques for measuring these parameters have been developed (e.g., Barnes 1983, Chalker et al. 1985), further research focused on applying these techniques to water quality assessment and reef monitoring are clearly needed.

Coral fecundity and recruitment

Two further individual-based coral parameters which Brown (1988) proposes as potentially useful indicators of sublethal stress on coral reefs are coral fecundity and recruitment. Tomascik and Sander (1987b) suggest that coral fecundity is decreased on reefs subject to increased eutrophication, while a number of studies (reviewed in Pearson 1981 and Brown 1988) have detected reduced coral recruitment and even recruitment failure due to a variety of environmental perturbations.

Additionally, ongoing research on pollutant effects on coral fecundity and recruitment (primarily out of the University of Guam) is focused on developing practical and effective methods for assessing coral reef condition and developing predictive tools to be applied to coral reef monitoring and management (Richmond 1993, 1994a, 1994b, 1995, 1996; Peters et al. 1997).

Presently accepted protocols, including the use of LC-50's on adult corals or coral reef proxies (e.g. *Tilapia*) are often inappropriate as well as inadequate for understanding the effects of pollutants on coral reefs. Work on cyanide exposure found some effects were not apparent until two weeks after exposure. In larval recruitment bioassays, larvae exposed to the golf course pesticide Chlorpyrifos had high survivorship, but significantly reduced abilities for recruitment. In a coral reef setting, lack of recruitment is equivalent to direct mortality (Richmond personal communication).

Different life-history stages of corals exhibit differential sensitivities to pollutants. Five chemically-mediated steps have been identified that affect the success of coral reproduction and recruitment:

1) reproductive synchronization among conspecific corals;
2) egg-sperm interactions;
3) embryological development;
4) larval settlement and metamorphic induction; and
5) acquisition of zooxanthellae (for most spawning species).

While adult corals may survive elevated levels of certain pollutants (e.g., organophosphate pesticides), the above five links may be affected by pollutants at extremely low levels.

Also, different substances will differentially affect different stages in the reproduction/recruitment cycle: hydrophilic substances will have a greater effect on reproductive synchrony, egg-sperm interactions and embryological development, while hydrophobic/lipophilic substances will affect settlement and metamorphic induction (Richmond 1996).

Research recommendation: Again, this area of research seems particularly promising, and is just starting to be applied in a systematic, calibrated fashion to water quality biomonitoring efforts on reefs. Research is needed to determine the effects of selected pesticides, PAH's and other potential pollutants on corals and coral reefs through the use of fertilization and recruitment bioassays. The use of adult corals (measuring growth rates, fecundity, and symbiotic associations) as well as their gametes and larvae as ecological indicators addresses the concern that mortality is a crude measure of environmental stress. Determining and measuring sublethal effects allow for a more proactive approach to monitoring and management.

Zooxanthellae loss

One oft-cited response of zooxanthellate reef organisms to a variety of stresses (both natural and anthropogenic) is the expulsion of symbiotic zooxanthellae, or "bleaching" (e.g., Gates and Brown 1985). As this phenomenon is both widespread and easily measured in a quantitative fashion, Brown (1988) and Jones (1997) have suggested that bleaching can serve as an excellent bioassay for assessing environmental stress on corals. Unfortunately, although zooxanthellae loss is a sensitive, sublethal response of corals to a wide range of environmental stressors (including temperature and salinity fluctuations and marine pollution), it is precisely this lack of a response specificity which limits its usefulness in bioassays.

Research recommendation: Bleaching may provide an early indication of stressful conditions upon a reef, but additional bioassays must be employed in order to identify the specific nature of the stressor and thus initiate corrective management actions.

Coral diseases and cyanobacterial blooms

Similar to the abovementioned indicator of zooxanthellae loss, monitoring the frequency and severity of occurrences of coral diseases has been proposed as an important metric of reef health (Richardson 1995). Particularly in the Florida Keys and Caribbean reef province as a whole, coral diseases such as black, white and red band disease are thought to have played an important role in reef degradation. Similarly, cyanobacterial blooms in the Florida Keys have been observed to completely cover large areas of reef, leading to the eventual death of the original benthic cover, especially the soft corals and gorgonians (Richardson 1995). Unfortunately, the causal factors involved in coral diseases and cyanobacterial blooms are poorly understood, though circumstantial evidence suggests that eutrophication may play a role, especially in cyanobacterial blooms. Nonetheless, incidence of coral diseases and algal/bacterial blooms are certainly an indicator of coral health, and clearly merit consideration for inclusion in biocriteria guidelines.

Research recommendation: Current research is focusing on determining the causal agents of coral diseases, as well as the relationship of disease incidence to surrounding water quality (Richardson 1995). Results from this research should determine the ultimate utility of these potential bioindicators. Further work should also focus on developing a standardized protocol for measuring incidence and severity of diseases and blooms, as well as interpretation of results.

Bioaccumulation of metals, phosphorus in coral skeletons

A final coral-based bioassay relies upon the bioaccumulating function of hard coral skeletons. A number of studies have revealed the tendency of hard corals to incorporate seawater contaminants such as trace metals and phosphorus into their skeletons during normal growth (Dodge et al. 1984, Brown 1988, Hanna and Muir, 1990). These studies have demonstrated that corals incorporate these contaminants in proportion to their ambient concentrations in the surrounding seawater, suggesting corals may be faithful long-term recorders of environmental water quality. Note, however, that at least one study (Brown and Holley 1982) found no apparent metals bioaccumulation by corals on an impacted reef flat where other organisms showed significant metal accumulation in tissues. Those authors suggest that one reason for the apparent discrepancy involves differences in the bioavailability of metals to the corals and other organisms; trace metals in solution in seawater undoubtably have different uptake routes than metals in particulate form. Even in those studies where corals did accumulate metals, an important complication is the finding that different species of coral from the same site demonstrate different uptake rates of trace metals (e.g., Hanna and Muir 1990). This finding suggests an active metabolic role of corals in the uptake of contaminants as opposed to simple passive uptake at ambient concentrations. Given this, it seems altogether possible that different individuals of the same species, living in different ambient conditions (with regard to depth, wave exposure, etc.) may also demonstrate different uptake rates of contaminants.

Research recommendation: While this bioaccumulation assay shows promise for reef water quality monitoring, it is apparent that further research is needed for a thorough understanding of the process of contaminant uptake by coral skeletons (including differences in the uptake of soluble and particulate fractions) and subsequent calibration of the skeletal signal to ambient water concentrations of the contaminant in question.

Physical damage

Jameson et al. (1997) in their rapid ecological assessment of 48 diving sites in the Egyptian Red Sea used quantitative line intercept transect data and qualitative quadrate data to evaluate physical damage before mooring buoys were installed. Baseline data from 1987 (Riegl and Velimirov 1991, Riegl and Velimirov 1994) was used as a yardstick to create the Reef Quality Index (a measure of acceptable coral reef aesthetic quality - not reef "health"). Diving sites did not meet acceptable standards for aesthetic quality if hard coral cover was < 30%, recently broken coral was > 5%, recently dead coral was > 3%, and rubble was > 5%. Unacceptable dive sites were then candidates for detailed monitoring and if necessary selected for recuperation or restoration programs.

Other researchers have used physical damage studies to estimate diving carrying capacities for coral reef ecosystems (Hawkins and Roberts 1996, Chadwick-Furman 1996, Dixon et al. 1993).

Research recommendation: In these types of studies one is never sure of the exact cause of physical damage (anthropogenic vs. nonanthropogenic). Reliable methods for controlling experimental conditions need to be developed. Historical baseline data also needs to be available to create an accurate and realistic Reef Quality Index.

Non-Coral Bioindicators

While a number of the above mentioned coral-based bioassays show strong potential, and the importance of including coral parameters in any reef monitoring program is irrefutable, a growing number of workers have advocated reef assessments which are more taxonomically-comprehensive in scope. Harger (1995) implores that "there is more to coral reef ecosystems than corals and fish," while Dustan and Hallas (1987) urge a "less myopic view of the reef" than is commonly taken in most coral monitoring schemes. The value of such "expanded" coral reef surveys was recently underscored in a large-scale assessment of the Kepulauan Seribu reefs near Jakarta, Indonesia where inclusion of stomatopod crustacean surveys in the monitoring protocol was instrumental in suggesting the cause of the drastic reduction in live coral observed (Erdmann and Sisovann, in press).

Erdmann and Caldwell (1997) list a number of non-coral bioindicators which have been proposed, formally or otherwise, for inclusion into reef monitoring programs worldwide. Many of the proposed reef bioassays are "borrowed" from successful temperate marine bioassessment programs, though they are often not as well-developed. Others are taken from primary literature reports, which often suggest the bioassay potential of various organisms which seem particularly affected by various anthropogenic impacts on reefs. In general, coral reef bioassessment is still in its infancy, lagging far behind the programs developed for aquatic and temperate marine biomonitoring. Nevertheless, many of the proposed non-coral bioindicators show great promise, as discussed below. A brief evaluation of each with respect to the bioindicator selection criteria in pages 31-35 should help direct future research efforts to refine these indicators into useable bioassays.

Butterflyfish

Undeniably, the most widely-discussed (and often misunderstood) bioindicators of environmental stress on coral reefs are the chaetodontids or butterflyfish, which have now been incorporated into a number of reef monitoring programs in the Indo-Pacific (Nash 1989, White 1989, Crosby and Reese 1996). Reese (1981) first gave a detailed definition of the butterflyfish bioindicator hypothesis, which has been re-stated again in Hourigan et al. (1988), Reese (1994), and Crosby and Reese (1996). In summary, this hypothesis states that for those species of butterflyfish which are obligate corallivores, a decline in the condition of a coral reef, manifested by decreasing food quality of the stressed coral polyps, will result in a decrease in the abundance and diversity of these species and an increase in territory size, feeding rate and agonistic encounters as mated pairs attempt to maintain their nutritional intake by expanding their territories to include more coral colonies. After a time, feeding rates may actually decrease as more time is spent defending territories from neighboring pairs.

Since the hypothesis was first published, a number of studies have shown a positive correlation between chaetodontid diversity and abundance and percent live coral cover (but not decreasing food quality of the stressed coral polyps) or coral species richness (e.g., Bell and Galzin 1984, Bouchon-Navaro et al. 1985, White 1989; but see Roberts and Ormond (1987) for conflicting evidence).

The often misunderstood aspect of the technique (which is not elucidated in Crosby and Reese 1996) is that: “the early warning function of the butterflyfish bioassay was never intended to be a direct indication of specific measured environmental stresses such as specific toxins” (Crosby, personal communication).

As such, the technique as presently outlined (Crosby and Reese 1996), is useful as a preliminary screening mechanism that could trigger more detailed studies to determine the specific cause of the decreasing food quality of the stressed coral polyps.

On a precautionary note, butterflyfish populations are sometimes subject to intensive human exploitation; not only are they favorite targets of marine aquarium collectors, they are often sought as food-fish in many developing countries (Erdmann 1997a). For this reason alone they are included in the Reef Check monitoring protocol - not as bioindicators of reef health, but as indicators of aquarium-collecting pressures (Hodgson 1997). Mechanisms must be incorporated into monitoring programs to insure that butterflyfishes are adequately protected from harvest and exploitation.

Research recommendation: To date, no research has yet quantitatively shown effects on butterflyfish abundance, diversity, feeding rate, territory size or aggressive encounters as a result of a specific chronic, sub-lethal stressor on hard corals. This and other concerns have led a large number of workers to question the relevance and utility of the butterflyfish bioassay (Roberts and Ormond 1987, Roberts et al. 1988, Brown 1988, Jones and Kaly 1996, Erdmann 1997a, Erdmann and Caldwell 1997).

To develop the butterflyfish bioassay into a response specific technique (i.e. take it beyond the preliminary screening tool phase) we recommend the following.

1. The "early warning" function of the butterflyfish bioassay needs to be substantiated. Although the butterflyfish bioindicator hypothesis suggests that sublethal degradation of coral reefs (manifested as decreasing food quality of the stressed coral polyps) can be detected by changes in the behavior and abundance of obligate corallivorous chaetodonts, available published data shows only correlations between chaetodont abundance and percentage live coral cover. To be of use to reef management programs, the bioassay must be able to detect such sublethal deterioration *before* a reduction in live coral cover occurs. If butterflyfish provide no early warning function before reductions in live coral cover occur, then one might as well directly monitor live coral cover.

2. The response specificity of the butterflyfish bioassay must be calibrated. Presently, if butterflyfish are simply responding to a reduction in live coral cover or food quality of coral polyps, monitoring their populations provides no insight into the specific stress causing these changes.

3. Following the above two points, the butterflyfish bioassay will also need a framework (statistical or numeric index-based) for interpreting the results of monitoring.

Ectoparasites on coral reef fishes

Evans et al. (1995) further suggest that measurement of the incidence of parasitism on coral reef fishes can provide an indirect measure of water quality conditions surrounding coral reefs. Previous authors have suggested that incidence of parasitism and/or disease may increase in "stressed" organismal populations (Esch et al. 1975, Gray 1989). In a study on the incidence of the isopod ectoparasite *Renocila* sp. on the coral reef fish *Abudefduf saxatilis* under varying pollution regimes, Evans et al. (1995) found weak evidence that parasite load was higher at heavily polluted sites than at less polluted sites.

Erdmann (1997b), however, examined the incidence of the gastropod ectoparasite *Caledoniella montrouzieri* on reef flat stomatopod assemblages in Indonesia and found no significant differences in parasite load between stomatopod assemblages at heavily polluted sites and relatively pristine sites. He suggested that some parasites, especially those with direct host transmission, may require high population densities of their host organisms for successful transmission. Host organisms which are sensitive to pollution and demonstrate reduced abundance under polluted conditions would therefore be unlikely to show increased incidence of parasitism with increasing pollution.

Other authors studying fish disease in polluted marine areas (e.g., McVikar et al. 1988) likewise suggest no clear correlation between pollution and incidence of disease/parasitism, and both Esch et al. (1975) and Gray (1989) conclude that the evidence for such a connection is equivocal at best.

Research recommendation: More evidence suggesting no clear correlation between pollution and incidence of disease/parasitism suggests this is not a potential bioindicator and would not warrant further consideration. However, research has not been extensive and further investigation may be fruitful.

Larval assemblages of fish and other reef taxa

One result of the stomatopod bioindicator work which appears to be common to similar studies on other reef organisms is the apparent extreme sensitivity of the larval and postlarval stages to water quality deterioration (Erdmann 1997b). This result has been reported by other workers for stomatopods (Gajbhiye et al. 1987), spiny lobsters (Herrnkind et al. 1988), and reef-flat gastropods (Garrity and Levings 1990). Likewise, Doherty (1991) proposes that the environmental sensitivity of larval coral reef fish assemblages makes them ideal candidates for reef biomonitoring studies.

Research recommendation: This suggestion obviously requires substantial additional research before larval fish assemblages can be used in an effective bioassay, but the broader implication here is that biomonitoring of a wide variety of reef organism larval and postlarval stages may prove an extremely sensitive method of detecting water quality deterioration. Future research efforts on reef bioindicators should certainly address this potential. An important obstacle to larval bioassays is the difficulty of reliably and quantitatively sampling larval assemblages (Erdmann 1997b). Doherty (1991) overcomes this problem by using expensive automated light traps, but these may well be outside the scope of most monitoring programs' budgets.

Indicators of Fishing/Shell Collecting

Both the Reef Check and ICLARM Aquanaut volunteer reef surveys include a number of "indicator species" of direct human exploitation of coral reefs in the form of fishing and collecting pressures (Hodgson 1997, McManus et al. 1997). Examples include edible holothurian species (trepang), giant clams (*Tridacna* sp.), mother-of-pearl shells (*Trochus* sp.), butterflyfishes (Chaetodontidae), large food fishes (e.g., Serranidae, Haemulidae) and spiny lobster (*Panulirus* sp.).

Research recommendation: While no formal interpretative framework is provided for assessing the results of monitoring the abundances of these groups, the intuitive appeal of indicators of fishing/collecting pressure suggests that this approach is worthy of further development for more rigorous use.

Organic contaminants and the development of fishes

Ongoing graduate work on Johnston Atoll by Lisa Kerr (personal communication) involves quantifying the effects of organic contaminants on the development of fishes. Kerr is trying to develop the use of the occurrence of developmental defects in a demersal spawning fish as a bioindicator of pollution effects. She has been studying colonies of the damselfish *Abudefduf sordidus* in areas contaminated with PCBs and will also be looking in areas contaminated with dioxins. Kerr's preliminary data suggests that with increasing sediment PCB concentration there is an increase in the occurrence of developmental defects. Her current study will track effects in the offspring of individual fish and then relate the level of effects in individuals to the individual's contaminant body burden.

Research recommendation: Contingent upon ongoing research results.

Bioaccumulation in molluscs and macrophytes

Bioaccumulation of trace metals and phosphorus by hard coral skeletons has been previously discussed, but several non-coral organisms have also been proposed as bioaccumulators of marine pollutants impinging on coral reefs. Specifically, Brown and Holly (1982) examined metals bioaccumulation by a macrophytic alga (*Padina tenuis*) and several molluscs, including the bivalves *Saccostrea cucullata* and *Isognomon isognomon* and the gastropod *Nerita chamaeleon*, on a reef flat affected by tin dredging and smelting. Their results showed that specimens of both bivalve species from the affected reef had elevated metals levels in their tissues relative to specimens from control sites, whereas the alga and the gastropod tissues showed no such clear pattern.

As discussed above, these authors suggest that differences in bioavailability of the metals (mostly in particulate form in this study) account for the differences between organisms: the filter-feeding bivalves consumed the metallic particulates, whereas the alga (and hence the herbivorous algal-feeding gastropod) were unaffected. Though additional studies of bioaccumulators are rare in the coral reef literature, temperate analogs of each of these organisms have been used extensively in bioassays worldwide (Bryan and Hummerstone 1973, Goldberg et al. 1978, Hungspreugs and Yuangthong 1984, Phillips 1994).

Two further issues involve the expense and relevancy of these bioassays. Chemical analysis of tissues for metals concentrations requires substantial money and equipment, two resources which small-scale monitoring programs may find in short supply. Furthermore, there is always the question of whether the pollutants being accumulated are even considered detrimental to reef health. Obviously, bioaccumulation assays should be limited to monitoring those pollutants with known impacts on coral reefs.

Research recommendation: While the same issues of calibration, bioavailability and differences in uptake mentioned above for coral bioaccumulators apply here, with further development these bioassays may be useful in some reef monitoring contexts as well.

Sessile reef organisms (sponges, gorgonians)

Alcolado et al. (1994) have suggested taxonomically-expanded surveys of the sessile reef community as an effective means of monitoring environmental conditions on reefs. These authors propose the use of two well-known diversity indices, H' (Shannon-Weaver heterogeneity index; Shannon and Weaver 1949) and J' (Pielou's evenness index; Pielou 1966), to evaluate environmental stresses on three groups of sessile reef taxa (scleractinians, gorgonians, and sponges). Specifically, they propose that calculation and comparison of H' and J' for each of these three taxonomic groups allows a rough classification of the environmental conditions faced by organisms on a particular reef. The environmental classification scheme proposed ranges from "favorable and predictable" (high values of both H' and J') to "unpredictably severe" (low values of both H' and J'). Using sponge communities in Cuba, the authors have developed and calibrated a numerical index for interpreting the various values of these diversity indices which they claim reliably segregates polluted reef stations. Unfortunately, the details of these investigations are reported in Cuban journals which were unavailable to the authors, preventing a detailed review of this technique.

Research recommendation: Although several workers (e.g., Green and Vascotto 1978) have argued against the use of diversity indices in water quality assessment, this technique appears worthy of further investigation. Potential issues regarding its appropriateness include questions about the early-warning function and response-specificity of the bioassay, as well as problems of taxonomic resolution (especially in the hyper-diverse Indo-Pacific).

Heterotrophic macroinvertebrates

Another promising, but largely undeveloped, set of bioassays of reef condition have been proposed based upon the well-documented ecosystem shift which has occurred on many reefs in urban, polluted areas. A number of workers have described a distinctive shift in pollution and sediment-stressed reefs from those dominated by coral-algal symbionts and reef fish towards those dominated by heterotrophic macroinvertebrates, especially scavengers, filter feeders, deposit feeders and internal bioeroders (Tomascik and Sander 1987a, Kinsey 1988, Tomascik et al. 1994, Risk et al. 1994). Organisms which are reported to have increased dramatically in abundance include zoanthids, sponges, barnacles, crabs, hydroids, tunicates, bioeroding (boring) sponges and bivalves, as well as a range of echinoid, holothurian and crinoid echinoderms (Dahl and Lamberts 1977, Dahl 1981, Dustan and Halas 1987, Kinsey 1988, Tomascik et al. 1994, Risk et al. 1994, Vail in press).

Abundance measures of a number of these taxonomic groups are already included in several reef monitoring programs (e.g., Dahl and Lamberts 1977, Dahl 1981, Risk et al. 1994, McManus et al. 1997, Hodgson 1997), apparently based upon the assumption that increases in abundance of these groups may indicate deteriorating environmental conditions on the surveyed reef.

Research recommendation: While these various organisms may very well prove to be excellent bioindicators of water quality deterioration, the sensitivity of their response has not yet been fully investigated and described. Clearly, the development and calibration of these potential bioassays should be a research priority. Data collected in the Reef Check and Aquanaut programs should also provide further evidence of the value of a number of these bioindicators.

Internal bioeroders

Of the above mentioned eutrophication bioindicators, one group, internal bioeroders, have been thoroughly investigated and have demonstrated a consistent, graded response of increasing abundance with increasing eutrophication on reefs (Rose and Risk 1985, Sammarco and Risk 1990, Risk et al. 1995, Holmes 1997). Holmes (1997) found that the proportion of dead coral rubble invaded by clionid sponges, as well as the number of invasions per rubble sample, increased dramatically with increasing eutrophication on reefs of Barbados. Rose and Risk (1985) found similar results with *Cliona* infestations of live *Montastrea cavernosa* heads in the Grand Caymans, while Sammarco and Risk (1990) and Risk et al. (1995) suggested that distinctive cross-continental shelf patterns of bioerosion (by sponges and bivalves) in *Porites* and *Acropora* on the Great Barrier Reef were explained primarily by increasing organic input with proximity to the mainland.

Research recommendation: Though this group has not yet been formally proposed for inclusion in biomonitoring programs, results of the above research suggest that internal bioeroders provide a sensitive assessment of increasing eutrophication on reefs and that development of a rigorous bioassay could be accomplished with minimal additional research.

Coelobites

Choi (1982) proposed that coelobite communities (reef cavity-dwellers such as foraminifers, bryozoans, tunicates, molluscs, sponges and serpulid worms) also respond in a sensitive manner to environmental stress, though in an opposite manner from that of internal bioeroders. His study on the effects of offshore drilling on coral rubble-dwelling coelobite communities showed a dramatic decrease in abundance of coelobites with proximity to the well-head, which he suggests is an effect of the greater concentration of drilling discharges close to the well-head. Drilling discharges were postulated to affect coelobites by direct smothering and/or iron toxicity.

In order to characterize the effects on community structure, Choi developed a numerical index whereby he assigned points to each community (rubble piece) sampled based upon the presence/absence and abundance of various coelobite groups. Using the results of his study, he calibrated the index and assigned interpretive meanings to various scores (e.g., scores of 10 or higher indicate a "healthy" or "recovering" coelobite community). While the widespread applicability of this bioassay has yet to be demonstrated (offshore drilling is a relatively uncommon stress to reefs), it may have potential for monitoring sedimentation stress on reefs. The method is particularly noteworthy in that it is one of the only examples of a calibrated numerical index of reef community health.

Research recommendation: Further research should focus on determining the sensitivity of this response relative to the hard coral community response to sedimentation (i.e., does it provide an early warning of increasing sedimentation, or is this parameter more easily measured by simple sediment traps?).

Foraminifers

Foraminifera are typically important contributors to reef sediments, especially species of larger foraminifera that host algal endosymbionts. Foraminiferal assemblages in reef sediments have been widely studied since 1922 primarily for the purpose of using analogies with modern biotas to interpret fossil assemblages and paleoenvironments for petroleum exploration. They are also easy and inexpensive to collect.

Cockey et al. (1996) show that published accounts of foraminiferal assemblages from sediments collected 30 or more years ago can be valuable resources in efforts to determine if biotic changes have occurred in coastal ecosystems and that family level identifications may be sufficient to detect decadal-scale changes in foraminiferal assemblages in reef sediments. Models formulated by Hallock and Schlager (1986), Birkeland (1987, 1988), and Hallock (1988) predict that community response to gradually increasing nutrient flux, whether natural or anthropogenic, should favor phytoplankton, benthic algae, and heterotrophic taxa lacking algal symbionts, rather than taxa that utilize algal symbionts for enhanced growth and calcification. Benthic succession along a nutrification gradient is a predictable response (Pearson and Rosenberg 1978) that has been commonly observed in foraminiferal assemblages (Lidz 1966, Alve 1995, Schafer et al. 1995). Pacific benthic foraminiferal assemblages have been observed to shift from predominantly algal symbiont-bearing species to dominance by small species lacking algal symbionts in response to a limited anthropogenic nutrient source (Hirschfield et al. 1968). Cockey et al. (1996) discuss how changes in foraminiferal assemblages, from dominance by algal symbiont-bearing taxa in 1959-1961 to heterotrophic taxa in 1982-1992, are consistent with predictions of benthic community response to gradually increasing nutrient flux into South Florida's *near coastal* waters by Szmant and Forrester (1996). The paucity of eutrophication-indicating foraminiferal taxa in sediments off Key Largo supports previous studies that show that anthropogenic nutrient influx has not caused eutrophication of reef and *open-shelf* environments in that area. Hallock et al. (1993a) predicted that at least a 10-fold increase in nutrients resources would be required to cause eutrophication in habitats occupied by mixed coral-algal communities in the Florida Keys.

Research recommendation: The use of foraminifera as bioindicators is very promising and new research should focus on creating and calibrating a multimeric index.

Stomatopod crustaceans

Stomatopod crustaceans were first proposed as bioindicators of marine pollution stress after a study on the effects of the 1986 Galeta, Panama oil spill indicated that these benthic reef-dwellers were highly sensitive to oil pollution (Jackson et al. 1989, Steger and Caldwell 1993). The results of that study showed that reef-flat stomatopods responded to heavy oiling by an initial, drastic decrease in abundance, followed by an extended period of reduced recruitment.

Based on these initial results, an evaluation of the bioindicator potential of Indonesian reef-flat stomatopod communities was initiated. The results of that 3-year study confirmed that stomatopod abundance, diversity and recruitment are strongly negatively correlated with sediment concentrations of petroleum hydrocarbons and selected heavy metals, and with surrogate measures of sewage and agrichemical runoff (Erdmann 1997b). In general, stomatopod communities show a strong trend of decreasing abundance and diversity with increasing proximity to major human population centers (Erdmann and Caldwell 1997, Erdmann and Sisovann in press). In addition to their demonstrated sensitivity to water quality degradation, stomatopods are abundant and ubiquitous throughout the world's reef provinces, and their taxonomy is readily taught to non-specialists. Reef-flat stomatopod assemblages in particular can be sampled quantitatively without the use of SCUBA, making them ideal candidates as inexpensive, low-tech bioindicators of reef water quality degradation.

Research recommendation: A further two-year project has recently been initiated with the goal of distilling the above results into a multimeric index of coral reef integrity, using as a model the successful benthic index of biotic integrity (B-IBI) developed for Tennessee Valley Authority bioassessment programs (Kerans and Karr 1994). The index will then be further calibrated based upon the results of comparative studies in 5 other regions of Indonesia (Erdmann in prep.). It is anticipated that the finalized stomatopod biomonitoring protocol will be completed in time for presentation at the 9th International Coral Reef Symposium in 2000 in Bali, Indonesia.

Amphipods

Because of their ecological importance, numerical abundance, and sensitivity to a variety of toxicants and pollutants, amphipod crustaceans have long been known as sensitive environmental indicators (Hart and Fuller 1979, Thomas 1993). Oakden et al. (1984) showed experimentally that temperate phoxocephalid amphipods actively avoided sewage and trace metal-contaminated sediments, preferring instead to burrow in “clean” sediments. Lacking a pelagic larval stage, amphipods are benthic recruiters, thereby minimizing dispersal effects. They show a high degree of habitat specificity and niche requirements and are one of the major benthic components in tropical marine ecosystems worldwide, in terms of biomass and species diversity. The use of amphipods in environmental monitoring has been limited to the few temperate regions where long-term taxonomic and natural history investigations have been undertaken. California currently uses amphipods as primary biological monitors at sewage outfalls. Monitoring programs incorporating amphipods have been used to assess the environmental effects of oil spills in the Persian Gulf, Alaska, and Panama. California and the Environmental Monitoring and Assessment Program (EMAP) program of EPA have designated several species of amphipods as bioassay organisms for sediment toxicity tests in soft-bottom environments (USEPA 1990b). Amphipods are so useful as bioindicators that US Government agencies now require their identification to the species level in permitting operations such as oil leases and outfalls. Their incorporation into bioassessment programs is dependent upon completion of comprehensive coastal resource inventories and taxonomic surveys (Thomas 1993).

In addition to acute and chronic sensitivities to pollutants and toxicants, amphipods exhibit a number of altered behavioral responses to sublethal levels of a variety of compounds that can cause reduction or elimination of the population (Baker 1971, Sandberg et al. 1972, Percy 1976, Linden 1976a & b, Lee et al. 1977). Amphipods are more sensitive than other species of invertebrates (decapods, polychaetes, molluscs, and asteroids) to a variety of contaminants (Ahsanullah 1976, Swartz et al. 1985, Swartz 1987). Amphipods also show responses to dredging, shoreline alteration, fishing practices, and changes in salinity and dissolved oxygen (Barnard 1958 & 1961, McLuskey 1967 & 1970, Widdowson 1971, Vobis 1973). In freshwater streams of Germany, the onset and recovery of 'stream souring' (acidification) has been documented since 1945 on the basis of distribution patterns of three species of the amphipod genus *Gammarus* (Meijefing 1991). This biological model has proved to be a more responsive and sensitive measure of environmental conditions than standard water quality protocols (Meijering 1991).

Ecological factors must also be considered in evaluating the potential information value of various amphipod groups. For example, in measuring the effects of an oil spill in a coral reef system, cryptofaunal and infaunal species of invertebrates may yield different patterns. Epifaunal forms could 'raft' in, while infaunal and cryptofaunal forms would have to recruit along the bottom from unaffected or minimally-impacted areas. Thus, the observed recolonization rates of the two groups, and subsequent interpretation of effects, could be quite different (Thomas 1993). In an actual oil spill on a Panama coral reef, two infaunal peracarid crustaceans (amphipods and tanaids) showed virtually no recovery after a 9-month period (Jackson et al. 1989), while other groups, including other crustaceans (brachyurans and burrowing shrimp), showed significant recovery at the same sites.

Research recommendation: Potential for amphipods as bioindicators exists in a wide variety of environments, especially in coral reefs, but their incorporation into such programs is dependent upon completion of taxonomic surveys and inventories.

Gastropod imposex

A well-substantiated bioassay with extreme sensitivity and response specificity is the evaluation of gastropod imposex as an indicator of tributyltin pollution in marine ecosystems around the world (Ellis and Pattisina 1990, Foale 1993, Gibbs and Bryan 1994). Imposex is the imposition of male sexual characteristics on female marine snails; its occurrence in snail populations generally signals exposure to tributyltin, an extremely toxic biocide which is still used in antifouling paints in a number of developing countries lacking strong environmental protection laws. Imposex as a result of tributyltin exposure (often at concentrations below the limits of chemical analytical detection) has been reported from over 45 species of neogastropod, including reef-associated species of the genera *Thais* and *Vasum* (Ellis and Pattisina 1990, Evans et al. 1995).

The occurrence and severity of imposex in a particular population is usually quantified using both frequency of imposex in females and the relative penis size index (RPS Index), calculated by dividing the mean ratio of penis weight to body weight for all females sampled by the mean ratio for the males (Foale 1993; note that other authors - e.g., Ellis and Pattisina 1990 - use penis length in calculating the RPS index instead). In populations which have not been exposed to tributyltin, both the frequency of female imposex and the RPS index is expected to be zero (or nearly so), as unaffected females do not normally develop a penis. In populations with tributyltin exposure, the frequency of imposex often reaches 100%, at which point the RPS index is necessary to differentiate the severity of exposure between populations (Ellis and Pattisina 1990).

Research recommendation: In monitoring situations where tributyltin exposure is a concern, measurement of gastropod imposex is a fully-developed bioassay with proven applicability to coral reef systems. The protocol is fast, inexpensive, and the results are easily interpreted. The only potential problem with its use can be the collection of sufficient sample sizes of the snails, which typically prefer "rocky shore" habitats (Evans et al. 1995).

Corallivores

Both of the above mentioned monitoring programs also advise recording abundances of corallivores such as the crown-of-thorns starfish (*Acanthaster planci*) and *Drupella* gastropods, which in "outbreak" situations have caused severe reef destruction on many reefs throughout the Pacific (Birkeland and Lucas 1990, Turner 1994). Though the proximal causes of outbreaks of these predators are still vigorously debated, their obvious relation to "reef health" makes them a logical choice in monitoring as well.

Research recommendation: Further research is obviously required to develop and calibrate a bioassay involving these corallivores.

Nitrogen isotope ratios and coprostanol levels in reef organism tissues

Although not a bioindicator *per se*, Risk et al. (1994) and Dunn (1995) have suggested the determination of stable isotope ratios of $^{15}N/^{14}N$ (denoted $\delta^{15}N$) in reef organism tissues as an excellent means of specifically evaluating the input of human faecal wastes into reef ecosystems. In studies in Zanzibar and the Maldives, tissues of reef corals from sites with heavy human sewage inputs showed significantly higher $\delta^{15}N$ values than coral tissues from relatively "clean" sites (Risk et al. 1994).

This technique is based upon the stepwise enrichment of $^{15}N/^{14}N$ ratios along increasing trophic levels, which is caused by the preferential elimination of the lighter isotope ^{14}N in urine and excretion products and the resulting $\delta^{15}N$ increase in organism tissues and faeces (reviewed in Peterson and Fry 1987). The technique is further predicated on the hypothesis that coral reef trophic structures with differing levels of sewage inputs will reflect these differences in the $\delta^{15}N$ signal at each trophic level. Those reefs with minimal sewage input should exhibit relatively low $\delta^{15}N$ values at each trophic level, indicative of oligotrophic conditions where algal fixation of atmospheric N ($\delta^{15}N=0$ by definition) is the major source of nitrogen. Conversely, those reefs which are strongly impacted by inputs of human faecal matter should show enriched $\delta^{15}N$ values, as a result of utilization of the relatively high $\delta^{15}N$ fecal matter as a primary nitrogen source at the base of the trophic structure.

Additional studies currently being conducted on corals in Java and Sulawesi, Indonesia, have substantiated the above results from Zanzibar and the Maldives (Risk personal communication).

Extension of the technique to other reef organisms has proved successful as well. Risk and Erdmann (in press) report that stomatopod tissues from the Spermonde Archipelago in Sulawesi show a dramatic, logarithmic increase in δ^{15}N with increasing proximity to Ujung Pandang, a coastal city of over one million residents with no primary sewage treatment.

Research recommendation: Continuing research on this bioassay, including comparative work in a number of different regions with varying human population levels, should result in the eventual calibration of a δ^{15}N index of sewage impacts on coral reefs. The technique has the disadvantage of requiring expensive analytical equipment (mass spectrophotometer), but the extreme sensitivity and replicability of results suggest that this assay could have widespread applicability with a number of reef taxa. In the Zanzibar/Maldives study, Risk et al. (1994) also suggested analyzing coral tissues for high concentrations of the sterol coprostanol, a breakdown product of cholesterol and hence a potential chemical indicator of human faecal waste. Results from coral sampling in the Maldives were inconclusive, but further research on this method is ongoing (Risk et al. 1994).

Changes in soft-bottom benthic community structure

Though not yet formally applied to coral reef ecosystems, a final set of bioassays worthy of mention are based on a large body of work examining pollution-induced changes in macrobenthic community structure in temperate soft-bottom communities. Extensive work by Pearson, Gray, Warwick, Clarke and associates has demonstrated a number of consistent, predictable responses in soft bottom community structure to increasing pollution, including a decrease in species richness, an increase in the total number of individuals due to a “retrogression to dominance by a few opportunistic species”, a reduction in the mean size of the average species or individual, changes in the shape of the log-normal distribution of individuals among species, and increased variability in species diversity indices such as H’ (Pearson and Rosenberg 1978, Gray and Mirza 1979, Gray 1981& 1989, Pearson et al. 1983, Warwick 1986, Clarke 1993, Warwick and Clarke 1993, but see Weston 1990 for contradictory evidence).

Brown (1988) has suggested that the above models may be inappropriate for coral reefs, as these habitats are much more highly-structured than soft bottom communities and thus may respond very differently. Nonetheless, the results of Tomascik and Sander’s (1987a) study on eutrophication effects on coral community structure correspond in part with this model, while a similar study by Clarke et al. (1993) demonstrates a breakdown in “seriation” (zonation pattern) in coral assemblages subject to sedimentation.

Research recommendation: A concerted research effort to apply the soft-bottom models to coral reef communities is clearly warranted. Furthermore, Brown (1988) suggests that even if these bioassays prove unworkable in a coral reef context, they may still be applicable to the soft-bottom communities which are often adjacent to coral reefs (lagoon bottoms and the base of reef slopes). An important consideration in applying the soft-bottom models to coral reef communities is that these models are based on *community* response to pollution. Coral reef studies tend to be more narrowly-focused, for example on *assemblages* of scleractinians or coral reef fish. Narrowing the taxonomic focus in studies of pollution effects may preclude detection of changes in the broader reef community (e.g., a decrease in coral cover with a corresponding increase in tunicate and sponge abundance). The difficulties in examining response of the entire community in highly diverse coral reef habitats may prevent the application of the soft-bottom bioassays to reef systems and is worthy of careful consideration.

FACT'97 coastal indicators

FACT is structured around nine strategic issues judged to be critical to the future of Florida's coast over the next 20 years (Bergquist et al. 1997). These broad strategic issues were refined into two-to-four sub-issues or components of each issue. These sub-issues then became the final framework around which indicators were developed. The nine issues and their associated sub-issues are as follows.

1) Impact of Growth in the Coastal Zone
- Impacts of Population Growth
- Patterns of Development
- Sufficiency of Infrastructure
- Economic Impacts

2) Disruption of Coastal Physical Processes
- Alteration of Existing Natural Systems
- Construction of Altering Structures

3) Responding to Coastal Threats and Hazards
- Coastal Hazard Mitigation
- Incompatible Living Areas
- Industrial Impacts

4) Degradation and Restoration of Coastal Ecosystems
- Habitat Change
- Species Population Trends
- Water Quality Trends

5) Managing Fresh Water Allocation
- Fresh Water Allocated for Ecological Maintenance
- Fresh Water Allocated to Meet Residential Needs
- Fresh Water Allocated to Meet Commercial/Industrial Needs
- Fresh Water Allocated to Meet Agricultural Needs

6) Sustaining the Human Uses of the Coast
- Maintenance of Recreational Value
- Sustainable Economic Use
- Balancing Development with Coastal Resources

7) Balancing Public and Private Uses of Resources
- Private Property Issues (no indicators have been developed for this sub-issue)
- Stewardship of Coastal Resources

8) Preservation of Cultural and Aesthetic Resources
- Preservation of Archaeological and historical Resources
- Preservation of Living Resources
- Conservation of Coastal Open Space

9) Encouraging Public Awareness and Involvement
- Public Awareness
- Public Participation

Research recommendation: The change in coral reef community dynamics indicator used by FACT is the coral reef/hard bottom monitoring facet of the FKNMS water quality monitoring program (Table 3.3). Relating other FACT indicators to coral reef ecosystem integrity will require the development of special indices and calibration.

Map-based indicators of potential threats to coral reef ecosystems

The World Resources Institute, in collaboration with the International Center for Living Aquatic Resources Management, the World Conservation Monitoring Center and the United Nations Environment Programme and a host of other coral reef experts, has created a system of evaluating potential threats (not actual reef condition) to coral reef ecosystems using map-based indicators (Burke et al. 1998). Results are based on a series of distance relationships correlating mapped locations of human activity, such as ports and towns, oil wells, coastal mining activities and shipping lanes (component indicators) with predicted risk zones of likely environmental degradation. Detailed sub-national statistics on population density, size of urban areas, and land cover type were also incorporated into the analysis. Data on rainfall and topography are used to estimate potential runoff within watersheds, from inland deforestation and agriculture. While still experimental, the "Reefs at Risk" indicators flag problem areas around the world where - in the absence of good management - coral reef degradation might be expected, or predicted to occur shortly, given ongoing levels of human activity.

Research recommendation: To make these indicators approach reality, a time factor must be incorporated into them, otherwise there is no feeling of urgency to the threats. Some of the map-based indicator assumptions need work as they are confounded by other factors or simply invalid.

Rapid assessment of management parameters (RAMP) for coral reefs

The University of Rhode Island's Coastal Resources Center (CRC) in collaboration with the International Center for Living Aquatic Resources Management (ICLARM) RAMP designed and field tested a set of indicators for assessing the human impacts (social, cultural and economic) on coral reefs. Indicators are organized according to proximity to the designated reef (e.g., national, regional and local), context (political, socioeconomic and cultural), reef uses (fishing, mining, tourism/recreational, etc.), and governance (institutional frameworks, knowledge bases, plans, implementation, monitoring and evaluation). A guide for information acquisition and subsequent coding for inclusion in ReefBase was also developed (Pollnac, 1997).

Research recommendation: Used together, RAMP and ReefBase have the potential to provide a baseline for monitoring changes in coral reef ecosystems as well as a standardized database for exploring interrelationships between the variables included. Defining and recording a standardized set of indicators is of critical importance. Presently, coastal zone and fisheries management literature is characterized by case studies conducted by many different individuals with unknown biases and varying research methodologies and disciplinary perspectives. When sufficient cases have been entered into these data sets, with data collected and coded using the standardized techniques developed, ReefBase and RAMP indicators will enable multivariate, quantitative analysis. Independent variables can be related to important dependent variables such as reef condition or management institution status to determine the amount of variance connected to the independent variables. Results of these analyses could provide decision makers with information that can be used to select alternative courses of action which will be based on more that the currently available unsystematic, anecdotal information (Pollnac, 1997). Relating RAMP indicators to coral reef ecosystem integrity will require the development of special indices and calibration.

DOES SUFFICIENT INFORMATION EXIST TO DRAFT BIOCRITERIA GUIDANCE?

While not exhaustive, the above list of proposed coral reef bioindicators covers a wide range of taxonomic groups and monitoring techniques. With a few notable exceptions (Table 7), the majority of these proposed bioassays have not yet been fully developed into useable monitoring protocols.

In these respects, coral reef bioindicators lag far behind freshwater and temperate marine biomonitoring programs, many of which have undergone extensive calibration and have been developed into multi-metric indices of "biotic integrity" with well-defined interpretative frameworks (e.g., Karr et al. 1986, Lenat 1988, Lang et al. 1989, Karr 1991, Rosenberg and Resh 1993, Kerans and Karr 1994, Wilson and Jeffrey 1994). Many of these indices result in the calculation of a simple numerical "score" for a particular site, which can then be compared over time or with other sites. Such rankings have an intuitive appeal to resource managers and users, and can be an effective means of galvanizing political willpower towards pollution prevention and conservation activities.

Table 7: Existing usable coral reef ecosystem related bioindices.

Index	Pollutant	Parameters	Status	Reference	Location
Calibrated Numerical Coelobite Index	Drilling discharges	Points assigned for presence /absence & abundance	Potential for monitoring sedimentation on coral is untested	Choi 1982	Pacific - Philippines
Gastropod Imposex - RPS Index	Tributyltin	Frequency of imposex in females and relative penis size	Fully developed	Ellis and Pattisina 1990	Caribbean, Pacific, Indian
Sessile Reef Diversity Index	Environmental conditions	Comparison of Shannon-Weaver heterogeneity index (H') & Pielou's evenness index (J')	Reported in Cuban journal and details un-available - but worth further investigation	Alcolado et al. 1994	Caribbean - Cuba
Nitrogen Isotope Ratios in Reef Organismal Tissues	Human (faecal) sewage $\delta^{15}N$ ratio of $^{15}N/^{14}N$	Fully calibrated for Indonesian coral reefs; further comparative work needed to test applicability to other geographic regions.	Risk et al. 1994 Dunn 1995 Risk & Erdmann (in press)	Indonesia (Zanzibar, Maldives)	

Potential Reference Sites For U.S. Coral Reef Ecosystem Biocriteria Program

The availability of reference sites and associated data bases are also requirements for a U.S. Coral Reef Ecosystem Biocriteria Program. Table 8 lists some minimally impaired coral reef ecosystems that potentially could serve as biocriteria reference sites.

Table 8: Sites under United States jurisdiction with minimally impaired coral reef ecosystems (Jameson et al. 1995b) that warrant further investigation as reference sites.

Site	Caribbean / Western Atlantic	Gulf of Mexico	Pacific
Dry Tortugas National Park	X		
Flower Gardens National Marine Sanctuary		X	
Northwest Hawaiian Islands (uninhabited)			X
Wake Island			X
Mariana Islands (less Guam & Saipan)			X
Palmyra Atoll			X
Kingman Reef			X
Howland Island			X
Baker Island			X
Jarvis Island			X
Fagatele Bay National Marine Sanctuary			X

The following coral reef ecosystems at risk within United States jurisdiction (Jameson et al. 1995b) warrant further investigation as they may have localized, minimally impaired areas that could be used as reference sites (Table 9).

Table 9: Coral reef ecosystems at risk within United States jurisdiction that warrant further investigation as reference sites.

Coral Reef Ecosystems At Risk	Caribbean / Western Atlantic	Gulf of Mexico	Pacific
Florida reef tract (less The Dry Tortugas)	X		
Puerto Rico	X		
United States Virgin Islands	X		
Main Hawaiian Islands (inhabited)			X
Johnston Atoll			X
Mariana Islands - Guam			X
Mariana Islands - Saipan			X
American Samoa			X

Conclusion

At this time, sufficient information does not exist to draft biocriteria guidance for coral reef ecosystems. However, the research progress to date, as outlined above, provides a good spring board for developing a U.S. Coral Reef Ecosystem Biocriteria Program.

WHAT RESEARCH AND/OR PROJECTS ARE NEEDED TO SUPPORT DEVELOPMENT OF BIOLOGICAL CRITERIA GUIDANCE FOR CORAL REEF ECOSYSTEM ASSESSMENT?

Coral reefs offer several distinct advantages as sites for bioassessment and biocriteria programs. They are discrete systems that occur within a narrow range of biological and physical parameters and exhibit comparable habitats over a wide geographical range. However, as shown in the previous chapter, comprehensive taxonomic surveys and inventories on which biocriteria programs are ultimately based are inadequate. Other constraints include the lack of active field systematists and adequate laboratory facilities in many U.S. possessions. Without substantial long-term commitments of facilities and personnel in tropical U.S. States and Possessions (particularly in the Pacific), these problems will continue to restrict progress in implementing biological assessment and biocriteria programs in coral reef areas.

The following recommendations for next steps to support development of biological criteria for coral reef ecosystem assessment are tasks that can be accomplished in the next 5 years. They complement the framework outlined in: *Draft Estuarine & Coastal Marine Waters Bioassessment & Biocriteria Technical Guidance* (Gibson et al. 1997).

1. RECOMMENDATION: Develop A Program Action Plan To Implement The U.S. Coral Reef Ecosystem Biocriteria Program

A Program Action Plan for the U.S. Coral Reef Ecosystem Biocriteria Program should be produced that clearly defines goals, objectives, budgets, responsible parties and timetables for accomplishing this important program. The economic and social consequences for not acting quickly are clear and serious (Jameson et al. 1995a).

2. RECOMMENDATION: Draft A U.S. Coral Reef Ecosystem Biocriteria Research Strategy And Disseminate It On The Internet

As discussed in the previous chapter, coral reef research relevant to biocriteria development lags far behind freshwater and estuarine results. A biocriteria research strategy needs to be developed and supported to provide the basic indicators and indices for the coral reef ecosystem biocriteria program. In designing the strategy, acceptable levels of uncertainty for decisions made on the basis of potential biocriteria should be considered and data quality objectives should be established. The final coral reef ecosystem biocriteria research strategy should be widely disseminated to the research community so interested scientists will have a clear framework to guide future research programs.

The present study can provide the basis for a small working group to draft the research strategy for peer review and EPA approval.

A web site for the U.S. Coral Reef Ecosystem Biocriteria Program should be developed (or tied into existing coral related web sites) to disseminate information on the program.

2.1 Build Upon Promising Areas Of Bioindicator Research In The Research Strategy

The review of current and proposed reef bioindicators in the previous chapter and Appendices 1-5 reveals a number of highly promising bioassays of water quality surrounding coral reefs. Further development of each of these biomonitoring protocols should not proceed in isolation; rather, the combination of a number of the bioindicator taxa into a multimetric coral reef index of integrity would be highly desirable and undoubtably more sensitive to a wider range of environmental perturbations than single-taxa bioassays. As suggested above, such indices should include at least some direct measures of the condition of hard coral assemblages, but should also include a variety of other taxa to ensure a taxonomically-comprehensive picture of current reef conditions.

Specific research and development needs for the majority of these bioassays include direct calibration of the indicator response to the environmental stress(es) it purports to monitor, comparative work in other geographic regions to test the widespread applicability of the assay, and development of an interpretative framework (preferably statistics-based) to allow standardized interpretation of biomonitoring results (e.g., a change in parameter ***x*** of ***y*** magnitude indicates an impact by ***a, b*** and/or ***c*** stressors and has ***z*** implications for reef biointegrity).

In some areas, basic faunal/floral inventories need to be conducted to identify tentative candidates for use as bioindicators before responses to various pollutants, toxicants, and other factors such as salinity, pH, dissolved oxygen, and temperature can be documented.

2.2 Conduct A Specially Designed Workshop To Suggest Potential New Bioindicators

A small, specially designed workshop should be conducted to include coral reef researchers, as well as researchers who have developed freshwater and estuarine bioindices, in order to get other perspectives on potential new bioindicators and the development of coral reef ecosystem biocriteria. This workshop would be designed in a way that would prepare participants in advance of the group meeting to address critical specific questions in their areas of expertise and important general questions relevant to the overall coral reef ecosystem biocriteria program.

2.3 Coordinate With Other Government Agencies To Fund The Research Strategy

EPA should work with other relevant government agencies, such as NOAA and NSF, to offer grants to accomplish the goals and objectives of the research strategy.

2.4 Select Coral Reef Ecosystem Bioindicators For The Research Strategy Using The Following Guidelines

Monitoring and assessment programs typically do not have the resources to measure all ecological attributes of concern to the public and to managers, and assessment tools must be cost-effective. Ideally, metrics selected for monitoring should be scientifically valid; should not require large amounts of expensive equipment nor extensive taxonomic identification; and should be relatively rapid in the field. The selected variables must be:

- **Related to Biological Integrity -** In general, almost any biological measurement is related to biological integrity, but some are more clearly tied to the properties of biotic systems of concern to society (e.g., native species, fish production, diverse trophic structure) (Suter 1993).

- **Responsive to Environmental Stresses -** Biological measurements and the metrics developed from them must respond to environmental stress. Metrics that are not monotonic (i.e., they do not consistently exhibit low values in response to one end of a stressor continuum and high values in response to the opposite end), or that respond oppositely to different **stresses,** are difficult to interpret in practice.

- **Measurable with Low Error -** Variability and measurement error should be controllable so that a reasonable sampling effort yields sufficient precision. Index period sampling (i.e., sampling during specific time periods in the annual cycle) is one way to reduce seasonal variability. However, there are costs in terms of information derived which may be prohibitive.

- **Cost-effective -** Cost of a metric should be proportional to the value of the information obtained. Usually, the simplest approach is most cost-effective and should be selected so long as results are sufficient to the agency's objectives.

- **Environmentally Benign to Measure -** Sampling methods that significantly disturb or alter habitats and biota should be avoided.

See pages 31-35 for more discussion on bioindicator selection.

2.5 Develop A Multimetric Approach For Coral Reef Ecosystem Survey Protocols

The recommended approach to employ in developing coral reef ecosystem survey protocols is to define an array of metrics or measures that individually provide limited information on biological status, but when integrated, function as an overall indicator of biological condition. This is generally referred to as a multimetric approach.

The best-documented responses to environmental stressors according to Gray (1989) are:

- reduction in species richness;
- change in species composition to dominance by opportunistic and tolerant species and;
- reduction in mean size of organisms.

However, because responses may vary under different stresses, it is desirable to incorporate many attributes into the assessment process (Gray 1989). The principal strength of the multimetric approach is its ability to integrate information from individual, population, community, and ecosystem levels to allow evaluation as a single, ecologically-based index of water resource quality (Karr 1991, Karr and Kerans 1992, Karr et al. 1986, Plafkin et al. 1989).

A metric is a calculated term or enumeration representing some aspect of biological assemblage structure, function, or other measurable characteristic. Similarly, each of the assemblages (e.g., fish, benthic macroinvertebrates) measured would be expected to have a response range to perturbation events or degraded conditions. Thus, biosurveys targeting multiple species and assemblages (i.e., multimetric) will likely provide detection capability over a broad range of impacts, and the biocriteria derived from their results could provide protection to a large segment of the ecosystem.

The multimetric approach is the best developed and most extensively used method to date. The multimetric concept came to fruition with the fish Index of Biotic Integrity (IBI) first conceived by Karr (1981). The IBI aggregates various elements and surrogate measures of process into a single assessment of biological condition. Karr (1981) and Karr et al. (1986) demonstrated that combinations of these attributes or metrics provide valuable synthetic assessments of the status of water resources. Wilson and Jeffrey (1994) review benthic biological pollution indices in estuaries. Time and experience will ultimately determine the best approach or combination for each state to use in coral reef ecosystem assessment.

Metrics can be expressed numerically as integers or ratios. Consistent routines in normalizing individual metric values provide a means of combining metric scores which initially consisted of dissimilar numerical expressions. However, final decisions on impact/no impact or management actions are not made on the single, aggregated value alone. Rather, if comparisons to established reference values indicate an impairment in biological condition, component parameters (or metrics) are examined for their individual effects on the aggregated value and for indications of potential causes.

Assessment of biological integrity using this multimetric approach typically focuses on four broad classes of community properties. Ecological systems respond to anthropogenic impacts with changes in one or more of these classes of properties (e.g., Karr et al. 1986, Schindler 1988, Plafkin et al. 1989, Schindler et al. 1989, Karr 1991, Barbour et al. 1992). The four properties are:

- **Health of populations**, typically expressed as number of individuals per ml or as biomass, reflecting possible stress from anthropogenic sources.

- **Community structure and composition,** or the number and kinds of species in an assemblage. Exotic species are typically undesirable, and high diversity is typically desirable. Species structure metrics can include diversity and evenness indexes as well as presence of indicator species, counts of tolerant or intolerant species, and the percentage of individual taxa in comparison to the total number sampled.

- **Trophic structure,** or the relative proportion of different trophic levels and functional feeding groups (e.g., Barbour et al. 1992). In estuaries, abundant, diverse, and relatively large top carnivores (e.g., piscivorous fish) are typically desirable as representative of a broad, stable, and substantial trophic network.

- **System function,** or the productivity and material cycling of the system or its components (trophic levels, assemblages, species). Measures of system function can include primary production, standing stock biomass, or abundance proportions of taxonomic groups (e.g., crustaceans, mollusks, polychaetes), or comparisons of infauna vs. epifauna. Too many or too few organisms, compared to reference systems, indicates low biological integrity.

Since biological integrity is defined as an indicator of undisturbed conditions, it too must be measured relative to those conditions. The requirement of the biological criteria process for a reference by which to measure biological integrity makes it a practical tool *(sensu* Peters 1991) for managing society's impact on the natural environment.

2.6 Use Multivariate Analysis To Refine Bioindicators

A complementary approach for biological criteria development is multivariate analysis of biological and physical data from reference sites. Many types of multivariate analyses are used by ecologists; ordination and discriminant analysis have proved most useful for the purposes of bioassessment. The purpose of ordination analysis is to reduce the complexity of many variables (for example, abundance of 100 species from multiple estuarine site classes) into fewer variables, such that the sites and the species are ordered on the new variables. This provides a rational reduction to the most consistent indicators for use in biocriteria.

Discriminant analysis is also used in biocriteria development to determine which variables discriminate between two or more *a priori* defined groups (e.g., presumed reference and impaired sites). Variables that accurately discriminate between groups are useful predictors for sites whose resource condition is not presumed *a priori.* These variables serve the same function in criteria development as metrics.

3. RECOMMENDATION: Establish Interagency Cooperation

The U.S. Coral Reef Ecosystem Biocriteria Program could benefit in many ways by establishing strong relationships with the following programs.

3.1 EPA - Environmental Monitoring and Assessment Program (EMAP)

The EPA - EMAP program worked with NOAA in conducting status and trends monitoring in the Florida Keys in the early 1990's. However, EMAP does not now have a coral reef component. The U.S. Coral Reef Ecosystem Biocriteria Program should work to establish monitoring programs with EMAP.

Other EMAP programs that could assist the U.S. Coral Reef Ecosystem Biocriteria Program include the following.

Ecological Indicator Development Program - presently does not have a coral reef component.

Demonstration of Intensive Sites Project (DISPRO) Index Sites Program - uses National Park sites for Term environmental monitoring and presently does not have a coral reef component. The Dry Tortugas National Park or the Virgin Islands National Park would be potential candidates for future DISPRO coral reef ecosystem sites.

3.2 EPA - Ecological Risk Assessment

While not an actual program, the EPA Risk Assessment Forum has issued guidelines (USEPA 1998) for ecological risk assessment that describe the framework for evaluating scientific information to determine the adverse effects of physical and chemical stressors on the environment. The U.S. Coral Reef Ecosystem Biocriteria Program should be valuable to complement and strengthen existing EPA ecological risk assessment guidelines in the area of coral reef ecosystem assessment.

3.3 NOAA - National Marine Sanctuaries Program

The U.S. Coral Reef Ecosystem Biocriteria Program should cooperate with the National Marine Sanctuaries Program in the:

- Designation of reference sites;
- Use of monitoring personnel;
- Data management; and
- Field logistical support.

3.4 NOAA - Special Projects Office - Coastal Assessment & Data Synthesis (CADS) Framework Team

Dr. Steve Rohmann (301-713-3000 x 137) of the CADS Framework Team has been working on coral reef benthic habitat classification for the Florida Keys National Marine Sanctuary since 1992 (Clarke and Rohmann 1994). They are producing a *Benthic Habitats of the Florida Keys* CD in May 1998 that will include the digital data for the habitat maps and a data publisher for creating habitat maps. The U.S. Coral Reef Ecosystem Biocriteria Program should make this office a “first stop” in their classification efforts and benefit from the experience in coral reef habitat classification gained by this NOAA office.

3.5 National Park Service

The U.S. Coral Reef Ecosystem Biocriteria Program should make special efforts to work closely with the Dry Tortugas National Park and Virgin Islands National Park. Both of these Parks can provide:

- Long-term monitoring data;
- Experienced personnel; and
- Can assist in the selection of reference sites.

3.6 CARICOMP - Puerto Rico And Florida Keys

The CARICOMP Program can also provide the U.S. Coral Reef Ecosystem Biocriteria Program with:

- Monitoring data;
- Experienced personnel; and
- Assistance in selecting reference sites.

3.7 Florida Center For Public Management

The Florida Coastal Management Program - Florida Department of Community Affairs, contracted with the Florida Center for Public Management to produce the FACT'97 and Florida Environmental Index Series. Aspects of both of these documents have the potential to be used in other coral reef areas outside of Florida.

4. RECOMMENDATION: Begin Preliminary Coral Reef Habitat Classification

Designing an appropriate habitat classification system for coral reef ecosystems under U.S. jurisdiction will, to some degree, depend on the type of bioindicators used for the U.S. Coral Reef Ecosystem Biocriteria Program. Ideally, the types of bioindicators used in the biocriteria program will allow for a very simplified habitat classification system (e.g., one that will not depend on a certain species or assemblage of coral to be present or require a certain geomorphological shape of the reef, etc.). A well designed biocriteria program and associated classification system will broaden the number of coral reef ecosystems that potentially can be used as reference sites. As research progresses, the types of bioindicators and indices to be used in the program will become clearer and this will allow for the development of the classification system.

NOAA 's Special Projects Office - Coastal Assessment & Data Synthesis (CADS) Framework Team, who conducted coral reef habitat classification work as part of the Florida Keys National Marine Sanctuary resource mapping program, can potentially provide valuable experience in this endeavor.

5. RECOMMENDATION: Begin Selecting Reference Sites And Developing Associated Data Bases

The process of evaluating and selecting reference sites can begin immediately. Selecting unimpaired reference sites in the Pacific will be easier than in the Western Atlantic and Caribbean, where population centers have impacted many coral reef ecosystems (Jameson et al. 1995).

Because absolutely pristine coral reef ecosystem habitats probably do not exist, resource managers must decide on acceptable levels of minimum impacts that exist or that are achievable in a given region. Acceptable reference conditions will differ among geographic regions and states because coral reef oceanographic conditions, gradients, trophic state, bottom sediment types, morphology and biological communities differ between regions.

Reference conditions can be established in a variety of ways but should include information derived from: historical data; reference sites; mathematical models; and consensus of expert opinion. It is important to recognize that the reference condition is best developed from a population of sites, not from a single site. However, in some instances, particularly coastal environments and sites influenced by controversial land uses, the use of site-specific nearfield/farfield stations may be necessary and appropriate to augment the reference condition.

- **Historical Data** - are usually available that describe biological conditions in the coastal marine region over some period of time in the past. Careful review and evaluation of these data provide insight about the communities that once existed and/or those that may be reestablished. Review of the literature and existing data is an important initial phase in the biocriteria development process. However, if data have not been collected for this specific purpose, they need to be carefully reviewed before being applied.

- **Reference Sites** - are minimally impaired locations in similar water bodies and habitat types at which data are collected for comparison with test sites. Reference sites could include: sites that are upstream of point sources; sites occurring along impact gradients (nearfield/farfield); and regional reference sites that may be applied to a variety of test sites in a given area.

- **Mathematical Models** - include mathematical models (logical constructs following from first principles and assumptions), statistical models (built from observed relationships between variables), or a combination of the two. The degree of complexity of mathematical models to predict reference conditions is potentially unlimited with attendant increased costs and loss of predictive ability as complexity increases (Peters 1991). However, models that predict biological reference conditions should only be used with great caution, because they are complex and often untestable hypotheses (Oreskes et al. 1994, Peters 1991).

- **Expert Opinion/Consensus** - A consensus of qualified experts is always needed for assessing all of the above information; establishing the reference condition; and helping develop the biocriteria. This is especially the case in impaired locales where no candidate reference sites are acceptable and models are deemed unreliable. In these cases, expert consensus is a workable alternative used to establish reference "expectations". Under such circumstances, the reference condition may be defined using a consensus of expert opinion based on sound ecological principles applicable to a region of interest. The procedures for these determinations and decisions should be well documented for the record.

Work should begin as soon as possible to compile all existing data on selected reference sites and organize the data into relational data bases.

5.1 Evaluate The Usefulness Of Appropriate Past Short-Term Monitoring Data

Many short-term or project specific monitoring efforts have been conducted, but repeating these is, in many cases, dependent on the cooperation of the personnel who conducted the original work. Data from these short-term monitoring efforts (less than 5 years in duration) could be useful building blocks for a U.S. biocriteria program and the potential of each of these efforts should be evaluated.

5.2 Designate Reference Sites As National Marine Sanctuaries

To ensure the long-term protection of reference sites special efforts should be made to work with NOAA to make the designation of reference sites as “research” national marine sanctuaries a top priority.

6. RECOMMENDATION: Develop U.S. Coral Reef Ecosystem Biocriteria Program Taxonomic Infrastructure

The following steps can be taken to insure that taxonomic necessities are addressed adequately in the U.S. Coral Reef Ecosystem Biocriteria Program.

- A complete taxonomic study and database for bioindicators used in the program should be maintained by taxonomically competent personnel.

- Nontechnical bioindicator identification guides should be prepared and updated as needed.

- A centralized collection of all bioindicator species should be maintained and curated for reference and research purposes.

- Competent taxonomic personnel should be provided by agencies involved in the U.S. Coral Reef Ecosystem Biocriteria Program.

- Develop agreements with relevant agencies to share data and information.

7. RECOMMENDATION: Initiate And Support National And International Watershed Management Programs.

The importance of healthy watersheds (and airsheds) to coral reef ecosystems can not be overstated. There are countless examples of declining fish and invertebrate species diversity and abundance in American rivers over the last century (Karr and Kerans 1991). If upstream biota are struggling for existence, it is not surprising that downstream residents (coral reef ecosystems) are hanging on for dear life.

In the U.S., it is encouraging to see the hundreds of local watershed management organizations (NGOs) being formed across the land to address clean water challenges. Over time, these local efforts to enforce total maximum daily load (TMDL) requirements for nutrients, sediments and bacteria, set by the federal government, will make a positive difference to estuarine and marine environments (i.e., coral reef ecosystems). It is also encouraging to see state governments across the U.S. also starting to initiate freshwater and estuarine biocriteria programs. International efforts by U.S. government agencies and NGOs should be made to help establish similar biocriteria and watershed management programs in countries with potential downstream impacts on U.S. coral reef ecosystems (see Florida reef tract example on pages 14-15). Without effective local upstream efforts on the national and international fronts a downstream US. Coral Reef Ecosystem Biocriteria Program will be, in the end, frustrated and ineffective.

ACKNOWLEDGEMENTS

This research was funded by the U.S. Environmental Protection Agency under contract (8W-0622-NASX) to Coral Seas Inc. - Integrated Coastal Zone Management. MVE would like to gratefully acknowledge the support of the U.S. National Science Foundation's International Research Fellows Program (No. INT-9704616).

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Appendix 1: Scleractinian coral bioindicators. References in bold are references which specifically mention the bioindicator potential of the parameter in question, those in plain text are primary literature which supports the utility of the bioindicator, while those in italics are literature which presents contradictory evidence or shows the proposed bioindicator to be inappropriate.

Bioindicator	**Protocol**	**Region**	**State**	**Season**	**References**
% Hard Coral Cover, Benthic cover diversity indices	"Traditional" reef monitoring parameters. Generally calculated using data from line intercept transects, but occasionally use belt transects, quadrats, and even manta tow.	Pacific Caribbean Indian		NA	**Dodge et al. 1982,** **DeVantier 1986,** **Gomez & Yap 1988,** **Aronson et al. 1994,** **English et al. 1994**
Coral vitality/mortality indices	Various models, but all calculate an index based on ratios of live and dead hard coral colonies. Some use data from LIT's, others use "random" searches for coral colonies of particular species. No formal interpretive framework.	Caribbean Pacific	Florida Keys Hawaii Philippines	NA	**Grigg & Dollar 1990,** **Dustan 1994,** **Gomez et al. 1994,** **Ginsburg et al. 1996**
Coral growth rate	Measurement of coral growth rates as an indication of water quality. Confused literature - some suggest growth rates decline with organic pollution, others suggest growth rates may increase. No formal interpretive framework.	Caribbean Pacific Indian		NA	**Brown 1988,** Hudson 1981, Cortes & Risk 1985, Rogers 1990, Brown & Howard 1985, *Tomascik & Sander 1985,* *Brown et al. 1990,* *Risk et al. 1995*
Productivity and calcification profiles	Measurement of productivity and calcification profiles as an indication of water quality. No formal interpretive framework.	Caribbean Pacific Indian		NA	**Barnes 1983,** **Brown 1988,** Chalker et al. 1985, McLanahan 1997

Bioindicator	Protocol	Region	State	Season	References
Coral fecundity and recruitment	Latest research from University of Guam looks at how different life-history stages of corals exhibit differential sensitivities to pollutants. Also, how different substances will differentially affect different stages in the reproduction/recruitment cycle. Formal interpretive framework under development.	Caribbean Pacific Indian	Guam	Dependent on local spawning/ settlement condt's	**Brown 1988,** Pearson 1981, Tomascik & Sander 1987b, **Richmond 1993, 1994a, 1994b, 1995 & 1996,** **Peters et al. 1997**
Zooxanthellae loss	Quantifying the occurrence and extent of coral bleaching as a general bioassay of environmental stress on corals. No formal interpretive framework.	Caribbean Pacific Indian		NA	**Brown 1988,** **Jones 1997**
Coral diseases and cyanobacterial blooms	Monitoring the frequency and severity of occurrences of coral diseases and cyanobacterial blooms. No formal interpretive framework.	western Atlantic	Florida	NA	**Richardson 1997**
Bioaccumulation of metals, phosphorus	Measurement of bioaccumulation of seawater contaminants in hard coral skeletons. No formal interpretive framework.	Caribbean Pacific Indian		NA	**Dodge et al. 1984,** **LeTissier & Brown 1988,** **Hanna and Muir 1990**
Physical damage	Measurement of physical damage to corals via transects or quadrates as an indicator of over use. The exact cause of physical damage is never totally certain.	Red Sea Caribbean		NA	**Jameson et al. 1997,** **Hawkins and Roberts 1996,** **Chadwick-Furman 1996,** **Dixon et al. 1993**

"No formal interpretive framework" means that the bioindicator in question has been proposed as a sensitive indicator of some environmental perturbation, but that a formal protocol for interpreting results has not yet been developed. For example, though coral bleaching or coral growth rates have been proposed as bioindicators, there are no guidelines for average growth rates or percentage of naturally-bleached colonies on a "healthy" reef versus growth rates or bleaching which signal water quality deterioration. By contrast, many freshwater biomonitoring programs have well-developed guidelines - for example, calculation of a numerical index, with a "formal interpretive framework" that a score of 20-25 indicates healthy river systems, 12-20 slightly impacted, etc..

Appendix 2: Fish bioindicators. References in bold are references which specifically mention the bioindicator potential of the parameter in question, those in plain text are primary literature which supports the utility of the bioindicator, while those in italics are literature which presents contradictory evidence or shows the proposed bioindicator to be inappropriate.

Bioindicator	Protocol	Region	State	Season	References
Butterflyfish (chaetodontids)	Monitoring hypothesis: for those species of butterflyfish which are obligate corallivores, a decline in the health of a reef, manifested by decreasing food quality of the stressed coral polyps, will result in a decrease in the abundance and diversity of these species and an increase in territory size, feeding rate and agonistic encounters as mated pairs attempt to maintain their nutritional intake by expanding their territories to include more coral colonies. After a time, feeding rates may decrease as more time is spent defending territories from neighboring pairs. Crosby and Reese (1996) outline a monitoring protocol which includes the use of 1-4, 30m line transects for visual census of butterflyfish abundance and live hard coral cover, as well as measurement of territory size, feeding and chasing behavior of individual pairs of target species. No formal interpretive framework.	Pacific	Hawaii Fiji	NA	**Reese 1981 & 1994,** **Hourigan et al. 1988,** **Nash 1989,** **White 1989,** **Crosby & Reese 1996,** Bell & Galzin 1984, Bouchon-Navaro et al. 1985, *Roberts & Ormond 1987,* *Roberts et al. 1988,* *Brown 1988,* *Jones & Kaly 1996,* *Erdmann 1997,* *Erdmann & Caldwell 1997*
Ectoparasites on coral reef fishes	Suggestion that the incidence of ectoparasitism on reef fishes should increase with deteriorating water quality. Used fish visual census technique of timed searches within 100m of shoreline. No formal interpretive framework.	Caribbean Pacific Indian		NA	**Evans et al. 1995,** Esch et al. 1975, *McVikar et al. 1988,* *Gray 1989*

Bioindicator	Protocol	Region	State	Season	References
Larval fish assemblages	Suggestion that the sensitivity of larval fishes, along with their position in the pelagic food web, make them excellent indicators of environmental perturbations. Collected using automated light traps. No formal interpretive framework.	Caribbean Pacific Indian		Dependent upon local spawning/ settlement conditions	**Doherty 1991**
Commercially valuable fish species as indicators of fishing pressure	Several monitoring protocols include censusing abundance of commercially valuable fish species to gauge fishing pressure. Target groups include food fishes (Serranidae, Haemulidae) and aquarium fishes (Chaetodontidae). No formal interpretive framework.	Caribbean Pacific Indian		NA	**Dahl 1981,** **Hodgson 1997,** **McManus et al. 1997**
Organic contaminants and the development of fishes	Uses the occurrence of developmental defects in a demersal spawning fish as a bioindicator of pollution effects (damselfish *Abudefduf sordidus* in areas contaminated with PCBs and will also be looking in areas contaminated with dioxins). Preliminary data suggests that with increasing sediment PCB concentration there is an increase in the occurrence of developmental defects.	Pacific	Johnston Atoll	N/A	Kerr (pers. com.)

"No formal interpretive framework" means that the bioindicator in question has been proposed as a sensitive indicator of some environmental perturbation, but that a formal protocol for interpreting results has not yet been developed. For example, though coral bleaching or coral growth rates have been proposed as bioindicators, there are no guidelines for average growth rates or percentage of naturally-bleached colonies on a "healthy" reef versus growth rates or bleaching which signal water quality deterioration. By contrast, many freshwater biomonitoring programs have well-developed guidelines - for example, calculation of a numerical index, with a "formal interpretive framework" that a score of 20-25 indicates healthy river systems, 12-20 slightly impacted, etc..

Appendix 3: Macrophyte bioindicators. References in bold are references which specifically mention the bioindicator potential of the parameter in question, those in plain text are primary literature which supports the utility of the bioindicator.

Bioindicator	Protocol	Region	State	Season	References
Macrophytes as metals bioaccumulators	Analysis of macrophytic algal tissues for bioaccumulation of heavy metal seawater contaminants. Utilizes atomic absorbtion spectrophotometry. Inconclusive results from coral reef study, shown effective in temperate marine systems. No formal interpretative framework.	Caribbean Pacific Indian		NA	**Brown & Holly 1982,** Bryan & Hummerstone 1973, Phillips 1974
Monitoring of macrophytic algal “blooms”	Several volunteer reef surveys (Aquanaut and Reef Check) suggest recording macrophytic algal blooms as an indication of high nutrient inputs on coral reefs (or overfishing of fish and invertebrate grazers). No formal interpretive framework.	Caribbean Pacific Indian		Not specified, though blooms are often highly seasonal - often correspond with wet season.	McManus et al. 1997, Hodgson 1997

"No formal interpretive framework" means that the bioindicator in question has been proposed as a sensitive indicator of some environmental perturbation, but that a formal protocol for interpreting results has not yet been developed. For example, though coral bleaching or coral growth rates have been proposed as bioindicators, there are no guidelines for average growth rates or percentage of naturally-bleached colonies on a "healthy" reef versus growth rates or bleaching which signal water quality deterioration. By contrast, many freshwater biomonitoring programs have well-developed guidelines - for example, calculation of a numerical index, with a "formal interpretive framework" that a score of 20-25 indicates healthy river systems, 12-20 slightly impacted, etc..

Appendix 4: Coral reef epifaunal bioindicators. References in bold are references which specifically mention the bioindicator potential of the parameter in question, those in plain text are primary literature which supports the utility of the bioindicator, while those in italics are literature which presents contradictory evidence or shows the proposed bioindicator to be inappropriate.

Bioindicator	Protocol	Region	State	Sea-son	References
Sessile reef community	Utilizes data from line intercept transects of sponge, gorgonian assemblages. Calculation of two well-known diversity indices, H' and J', and comparison of their relative values allows a classification of environmental conditions (favorability and predictability) on a reef.	Caribbean	Cuba	NA	**Alcolado et al. 1994**
Heterotrophic macroinvertebrates	Largely undeveloped, based upon the well-substantiated observation that many pollution-stressed reefs undergo an "ecosystem shift" from those dominated by coral-algal symbionts towards those dominated by heterotrophic macroinvertebrates, especially scavengers, filter feeders, and internal bioeroders. Abundance measures of many of these groups are included in several current monitoring schemes, but no formal interpretive framework is in place at this time.	Caribbean Pacific Indian		NA	**Dahl 1981,** **Dustan & Halas 1987,** **Risk et al. 1994,** **Hodgson 1997,** **McManus et al. 1997,** Tomascik & Sander 1987a, Kinsey 1988, Tomascik et al. 1994, Vail (in press)

Bioindicator	Protocol	Region	State	Sea-son	References
Internal bioeroders	Studies in both the Caribbean and Pacific have shown conclusively that the proportion of rubble (or live coral colonies) invaded by bioeroding sponges and bivalves, as well as the number of invasions per rubble sample increase with increasing eutrophication. Not formally proposed as bioindicator, but obvious potential.	Caribbean Pacific Indian		NA	Rose & Risk 1985, Sammarco & Risk 1990, Risk et al. 1995, Holmes 1997
Coelobites (reef cavity-dwellers)	Shown that coelobites such as foraminifers, bryozoans, tunicates, molluscs and serpulid worms decrease in abundance with proximity to an offshore oil drilling well-head. Developed numerical index with points assigned for presence/absence and abundance of various coelobites in each rubble piece, with resulting index used to classify reef health.	Pacific	Philippines	NA	Choi 1982
Foraminifers	Community response to gradually increasing nutrient flux, whether natural or anthropogenic, favors phytoplankton, bnethic algae, and heterotrophic taxa lacking algal symbionts, rather than taxa that utilize algal symbionts for enhanced growth and calcification. Benthic succession along a nutrification gradient is a predictable response that has been commonly observed in foraminiferal assemblages.	Caribbean Pacific Indian		NA	**Hallock-Muller 1996,** **Hodgson 1997,** **Cickey et al. 1996**

Bioindicator	Protocol	Region	State	Sea-son	References
Bioaccumulation in molluscs	Very well-developed bioassay in temperate systems (eg, Musselwatch), not very developed in reefal areas. Filter-feeding bivalves and grazing gastropods are sampled for metals bioaccumulation using atomic absorbtion spectrophotometry. No formal interpretive framework.	Caribbean Pacific Indian		NA	**Brown and Holly 1982,** Goldberg et al. 1978, Hungspreugs & Yuangthong 1984
Stomatopod crustaceans	Bioassay still under development. Studies from both the Caribbean and Pacific show conclusively that stomatopod abundance, diversity, and recruitment are strongly negatively correlated with various pollution measures. No formal interpretive framework.	Caribbean Pacific Indian		NA	**Steger & Caldwell 1993,** **Erdmann 1997b,** **Erdmann & Caldwell 1997,** Erdmann & Sisovann (in press)
Amphipods	In addition to acute and chronic sensitivities to pollutants and toxicants, amphipods exhibit a number of altered behavioral responses to sublethal levels of a variety of compounds that can cause reduction or elimination of the population. Amphipods are more sensitive than other species of invertebrates (decapods, polychaetes, molluscs, and asteroids) to a variety of contaminants. Amphipods also show responses to dredging, shoreline alteration, fishing practices, salinity, and dissolved oxygen.	Caribbean Pacific Indian		NA	**Thomas 1993,** **Oakden et al. 1984,** **Baker 1971,** **Sandberg et al. 1972,** **Percy 1976,** **Linden 1976a & b,** **Lee et al. 1977,** **Ahsanullah 1976, Swartz et al. 1985, Swartz 1987,** **Barnard 1958 & 1961,** **McCluskey 1967 & 1970,** **Widdowson 1971, Vobis 1973**

Bioindicator	Protocol	Region	State	Sea-son	References
Gastropod imposex	Well-developed bioassay. Gastropod imposex (imposition of male sexual characters on females) is extremely sensitive indicator of exposure to tributyl tin. Occurence and severity of imposex in a particular population is quantifiedusing both frequency of imposex in females and relative penis size index - mean ratio of penis weight to body weight for all females divided by same ratio for males.	Caribbean Pacific Indian		NA	**Ellis & Pattisina 1990,** **Foale 1993,** **Gibbs & Brya 1994,** **Evans et al. 1995**
Corallivores	Records abundance of corallivores such as crown-of-thorns starfish (*Acanthaster planci*) and *Drupella* gastropods. No formal interpretive framework.	Pacific		NA	Birkeland & Lucas 1990, Turner 1994
Larval assemblages of other reef taxa	Suggestion that the sensitivity of larval stomatopods, spiny lobster and reef-flat gastropods make them excellent indicators of environmental perturbations. No formal interpretive framework.	Caribbean Pacific Indian		Dependent upon local spawning/ settlement conditions	**Erdmann 1997b,** Gajbhiye et al. 1987, Herrnkind et al. 1988, Garrity & Levings 1990

"No formal interpretive framework" means that the bioindicator in question has been proposed as a sensitive indicator of some environmental perturbation, but that a formal protocol for interpreting results has not yet been developed. For example, though coral bleaching or coral growth rates have been proposed as bioindicators, there are no guidelines for average growth rates or percentage of naturally-bleached colonies on a "healthy" reef versus growth rates or bleaching which signal water quality deterioration. By contrast, many freshwater biomonitoring programs have well-developed guidelines - for example, calculation of a numerical index, with a "formal interpretive framework" that a score of 20-25 indicates healthy river systems, 12-20 slightly impacted, etc..

Appendix 5: Other bioindicators. References in bold are references which specifically mention the bioindicator potential of the parameter in question, those in italics are literature which presents contradictory evidence or shows the proposed bioindicator to be inappropriate.

Bioindicator	Protocol	Region	State	Season	References
Nitrogen isotope ratios	Stable isotope ratios of $^{15}N/^{14}N$ (denoted $d^{15}N$) in reef organism tissues have been shown to be an excellent indicator of human faecal waste inputs on coral reefs. Calibration of $d^{15}N$ is necessary for each specific organism and region, but very powerful and accurate means of assessing this form of organic enrichment. Uses mass spectrophotometer to measure $d^{15}N$.	Caribbean Pacific Indian		NA	**Risk et al. 1994,** **Dunn 1995,** **Risk &Erdmann (in press)**
Soft-bottom benthic community structure	Used extensively in temperate marine ecosystems, but not yet applied to coral reefs. Large body of work shows consistent, predictable responses in soft bottom community structure to increasing pollution, including decrease in species richness, increase in total number of individuals, reduction in the mean size of the average species or individual, changes in shape of log-normal distribution of individuals among species, and increased variability in species diversity indices. Needs further research to apply to coral reefs.	??		NA	**Pearson & Rosenberg 1978,** **Gray & Mirza 1979,** **Gray, 1981 & 1989** **Pearson et al. 1983,** **Warwick 1986,** **Bilyard 1987,** **Clarke 1993,** **Warwick & Clarke 1993,** *Brown 1988,* *Weston 1990*
FACT'97 coastal indicators	The change in coral reef community dynamics indicator used by FACT is the coral reef/hard bottom monitoring facet of the FKNMS water quality monitoring program (Table 3.3). Relating other FACT indicators to coral reef ecosystem integrity will require the development of special indices and calibration.	western Atlantic	Florida	NA	**Bergquist et al. 1997**

Bioindicator	Protocol	Region	State	Sea-son	References
Map-based indicators of potential threats to coral reefs	While still experimental, the “Reefs at Risk” indicators flag problem areas around the world where - in the absence of good management - coral reef degradation might be expected, or predicted to occur shortly, given ongoing levels of human activity. Results are based on a series of distance relationships correlating mapped locations of human activity, such as ports and towns, oil wells, coastal mining activities and shipping lanes (component indicators) with predicted risk zones of likely environmental degradation. Detailed sub-national statistics on population density, size of urban areas, and land cover type were also incorporated into the analysis. Data on rainfall and topography are used to estimate potential runoff within watersheds, from inland deforestation and agriculture. To make these indicators approach reality, a time factor must be incorporated into them, otherwise there is no feeling of urgency to the threats. Some of the map-based indicator assumptions need work as they are confounded by other factors or simply invalid.	Global	Global	NA	**Burke et al. 1998**

Bioindicator	**Protocol**	**Region**	**State**	**Sea-son**	**References**
RAMP indicators for assessing the human impacts (social, cultural and economic) on coral reefs	Indicators are organized according to proximity to the designated reef (e.g., national, regional and local), context (political, socioeconomic and cultural), reef uses (fishing, mining, tourism/recreational, etc.), and governance (institutional frameworks, knowledge bases, plans, implementation, monitoring and evaluation). A guide for information acquisition and subsequent coding for inclusion in ReefBase was also developed. Relating RAMP indicators to coral reef ecosystem integrity will require the development of special indices and calibration.	Pacific Caribbean	Philippines Jamaica	NA	**Pollnac, 1997**

ATOLL RESEARCH BULLETIN

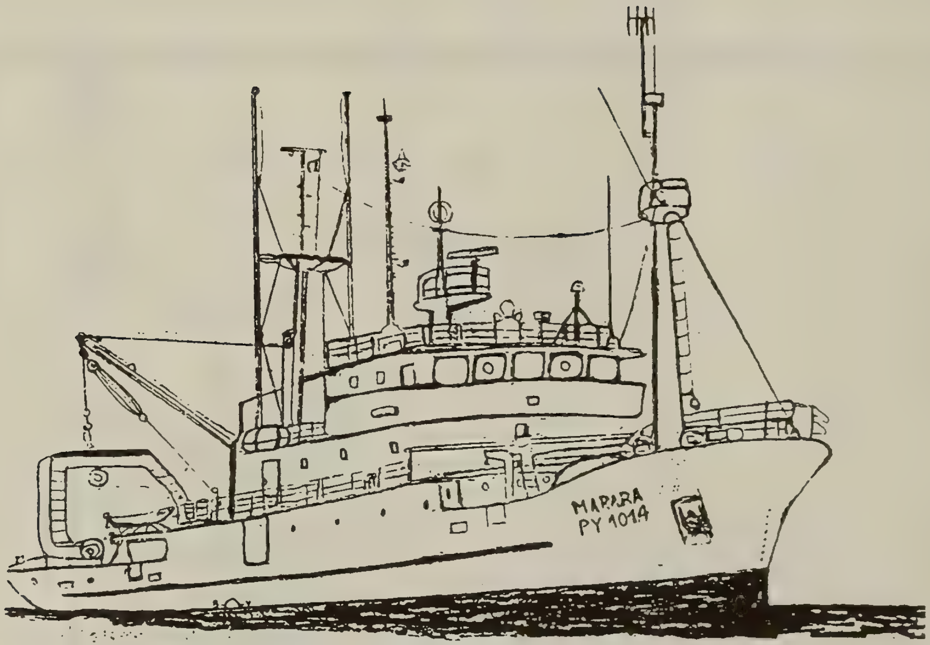
NO. 451

CRUSTACEA DECAPODA AND ST~~R~~OMATOPODA OF FRENCH POLYNESIA

BY

JOSEPH POUPIN

ISSUED BY
NATIONAL MUSEUM OF NATURAL HISTORY
SMITHSONIAN INSTITUTION
WASHINGTON, D.C., U.S.A.
SEPTEMBER 1998



RV *Marara*, 43 m long; original drawing by a Polynesian
This vessel has operated in French Polynesia between 1973 and 1996, and realised important collections of Crustacea.

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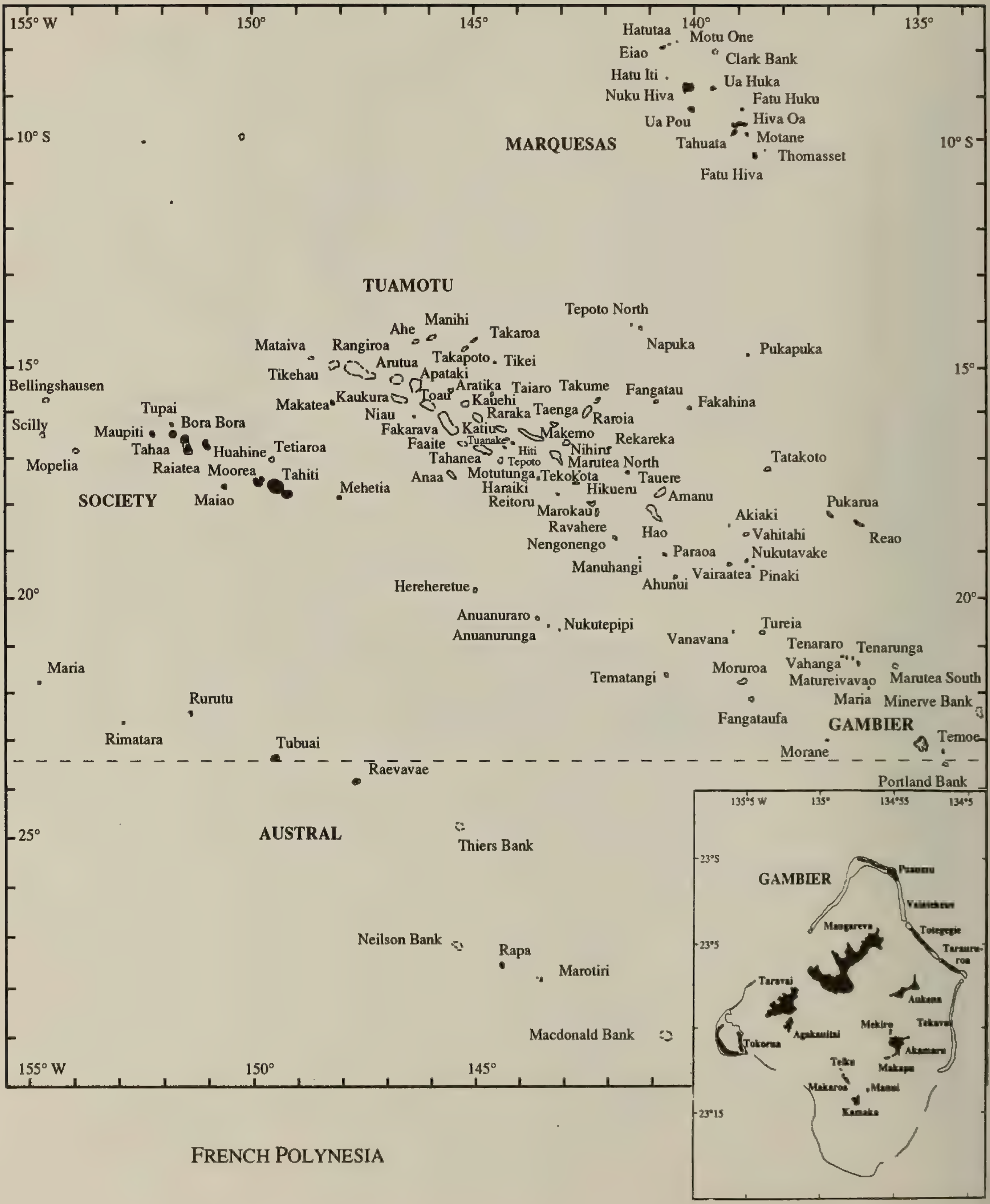

FRENCH POLYNESIA

CRUSTACEA DECAPODA AND STOMATOPODA
OF FRENCH POLYNESIA

(DENDROBRANCHIATA, STENOPODIDEA, CARIDEA, THALASSINIDEA, AND STOMATOPODA, WITH ADDITIONS TO ASTACIDEA, PALINURIDEA, ANOMURA, AND BRACHYURA)

BY

JOSEPH POUPIN

ABSTRACT

French Polynesian Decapoda, restricted to shrimps, and Stomatopoda are inventoried from literature and unpublished fields collections. Number of species is 205 for the shrimps and 26 for the Stomatopoda. Within the shrimps, Caridea dominate with 170 species, mainly Alpheidae (57 species), Palaemonidae (46 species), and Pandalidae (29 species). Full literature and distribution in French Polynesia are indicated for each species. When available a brief indication is also given on the biotop. New records include 23 species of the genera *Aristaeomorpha*, *Funchalia*, *Metapenaeopsis*, *Pelagopenaeus*, *Sicyonia*, *Nematocarcinus*, *Janicella*, *Stylodactylus*, *Anchistus*, *Harpiliopsis*, *Jocaste*, *Paranchistus*, *Periclimenes*, *Philarius*, *Vir*, and *Thor*, for the shrimps, and *Alima*, *Busquilla*, and *Gonodactylus*, for the Stomatopoda.

Modifications to the first documented checklist of the French Polynesian lobsters, hermit crabs, and crabs (POUPIN, 1996a) are also included with 28 additional species of the genera *Stereomastis* and *Panulirus* for the lobsters, *Calcinus*, *Dardanus*, *Catapagurus*, *Nematopagurus*, *Pylopaguropsis*, *Oncopagurus*, *Munida*, and *Albunea* for the hermit crabs, *Calappa*, *Mursia*, *Alainodaeus*, *Hexagonalia*, *Tetralia*, *Trapezia*, *Lithoscapus*, *Sphenomaia*, and *Utinomiella*, for the crabs.

The total number of French Polynesian Decapoda and Stomatopoda is now 758, mainly Brachyura (377 species), Caridea (170 species), and Anomura (126 species). Modern researches alone, *i.e.* published after 1980, have generated 322 new records. Despite these efforts, knowledge of the regional fauna remains incomplete, and it is estimated that the number of species will easily exceed 800 when recent collections from the Marquesas are fully studied (MUSORSTOM 9). A lot of genera still need a careful revision and groups like the Thalassinidea and Stomatopoda are obviously under-represented.

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Manuscript received 26 March 1998; revised 12 June 1998

INTRODUCTION

In complement to the first documented checklist dealing with the Astacidea, Palinuridea, Anomura, and Brachyura (POUPIN, 1996a), the present work considers the shrimps (Dendrobranchiata, Stenopodidae, Caridea, and Thalassinidea) and Stomatopoda of French Polynesia.

Deep shrimps, *i.e.* beyond 100m, were originally listed separately by POUPIN in: "Recent contributions to the deep sea decapod Crustacea of French Polynesia", submitted to the *Proceedings of the International Senckenberg Symposium*, Frankfurt, October 1993. However, as these Proceedings were never printed, they are again included here. This deep material mainly comes from investigations of the RV *Marara* (POUPIN, 1996b; POUPIN & BENARD, 1996).

Records from the literature are complemented by unpublished field collections. These were made by the author, during the RV *Marara* campaigns, or realised during the activities of the French ORSTOM research center, Tahiti.

Presentation follows POUPIN (1996a) and is briefly summarized here. Records are limited to French Polynesia, which includes five archipelagos: Marquesas, Society, Austral, Tuamotu, and Gambier Islands (see map). A single exception is for *Metapenaeopsis velutina*, recorded by CROSNIER (1991) from Pitcairn Island in the neighbourhood of the Gambier Islands. The unit of location is the Island, names of bays, rivers, or islets on the reef (Polynesian 'Motu') being ignored. It must be noted that distribution patterns of most of the species are well beyond French Polynesia but are strictly limited to French Polynesia in this report. As far as possible, we briefly mentioned the main characteristic of the biotop: freshwater, pelagic, bathypelagic, planktonic, sublittoral, deep, burrower, and association with other organisms (coral, echinoderm, sponge...). This information, for example depth range or kind of association, is restricted to observations made in French Polynesia. Arbitrarily, (see POUPIN, 1996a: 7) "Sublittoral" means between 10-100m, and "Deep" beyond 100m. When no depth range is indicated it means that the species is common in littoral shallow waters. A brief history of the collections is related under each Infra-Order section.

Abbreviations are: MNH, Museum of Natural History, London; BPBM, Bernice P. BISHOP Museum, Honolulu; CRIOBE, Centre de Recherche Insulaire et Observatoire de l'Environnement, Moorea; MNHN, Muséum national d'Histoire naturelle, Paris; ORSTOM, Institut Français de Recherche Scientifique pour le Développement en Coopération; RMNH, Nationaal Natuurhistorisch Museum, Leiden; RV, Research Vessel; SME, Station Marine d'Endoume; USNM, National Museum of Natural History, Washington.

LIST OF THE SPECIES

ORDER DECAPODA

INFRA-ORDER DENDROBRANCHIATA

Dendrobranchiata reported here are mostly pelagic, bathypelagic, or deep species. Oldest collections were made by the HMS *Challenger* (BATE, 1881, 1888). Subsequent species were then collected by the

National Geographic Society SMITHSONIAN-BISHOP Museum Marquesas Expedition (REHDER, H.A., 1967[1], CROSNIER, 1991). Recent additions to the Dendrobranchiata mainly come from RV *Marara* collections (POUPIN *et al.*, 1990; POUPIN, 1996b) or material from the ORSTOM Center, Tahiti (coll. P. FROUIN, E. JOSSE, and RV *Alis* Marquesas Expedition, August/September 1997). This material has been determined by A. CROSNIER (MNHN) and includes 7 species reported for the first time: *Aristaeomorpha foliacea*, *Funchalia taaningi*, *F. villosa*, *Metapenaeopsis commensalis*, *M. hilarula*, *Pelagopenaeus balboe*, and *Sicyonia* sp.

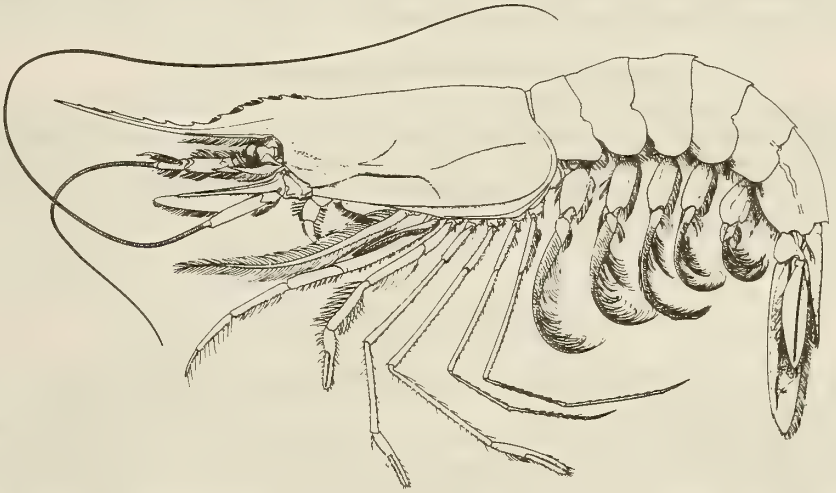

Figure 1 - *Aristaeomorpha foliacea* Risso, 1827
(Drawing by M.K. RYAN, in PÉREZ FARFANTE & KENSLEY, 1997)

FAMILY ARISTAEIDAE

Aristaeomorpha foliacea Risso, 1827

DISTRIBUTION. — Society (Maupiti) - *Bathypelagic* (718m).
REFERENCES. — ***Aristaeomorpha foliacea*** - NEW MATERIAL - Coll. RV *Marara*, det. A. CROSNIER (Maupiti MNHN Na13433; 718m).

Aristeus aff. *mabahissae* Ramadan, 1938

DISTRIBUTION. — Marquesas (Eiao, Hiva Oa) - *Bathypelagic (600-630m)*.
REFERENCES. — ***Aristeus* aff. *mabahissae*** - POUPIN *et al.*, 1990: 15 (French Polynesia). — POUPIN, 1996b: 4, pl. 1a (Eiao, Hiva-Oa; 600-630m).

Plesiopenaeus armatus (Bate, 1881)

DISTRIBUTION. — Tuamotu - *Bathypelagic (4300m)*.
REFERENCES. — ***Aristeus armatus*** - BATE, 1888: 312, pl. 45-46 (Northwest Tuamotu, *Challenger* st. 276, 16/09/1875, 13°28'S, 149°30'W). — ***Plesiopenaeus armatus*** - CROSNIER & FOREST, 1973: 294, fig. 99c-d (Syn.).

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[1] Erroneously mentioned as "HARALD, 1967" in POUPIN 1996a

FAMILY BENTHESICYMIDAE

Benthesicymus crenatus Bate, 1881

DISTRIBUTION. — Tuamotu - *Bathypelagic (4300m).*

REFERENCES. — ***Benthesicymus crenatus*** Bate, 1881: 191; 1888: 329, pl. 54-55 (Northwest Tuamotu, *Challenger* st. 276, 16/09/1875, 13°28'S, 149°30'W).

Benthesicymus investigatoris Alcock & Anderson, 1899

DISTRIBUTION. — Marquesas (Hiva Oa); Society (Huahine); Tuamotu (Makemo) - *Bathypelagic (630-1025m).*

REFERENCES. — ***Benthesicymus investigatoris*** - POUPIN *et al.*, 1990: 15 (French Polynesia). — POUPIN, 1996b: 4, pl. 1b (Hiva Oa, Huahine, Makemo; 630-1025m).

Benthesicymus strabus Burkenroad, 1936

DISTRIBUTION. — Austral - *Bathypelagic (4346m).*

REFERENCES. — ***Benthesicymus brasiliensis*** Bate 1888: 332, pl. 57-fig. 1 (Southeast of Marotiri, *Challenger* st. 285, 14/10/1875, 32°36'S, 137°43'W, 4346m), *Challenger* specimens from the South Pacific are not *B. brasiliensis* Bate, 1888 but *B. strabus* nov. in BURKENROAD (1936: 29) — ***Benthesicymus strabus*** Burkenroad, 1936: 29, 32, 33, 42, 46, fig. 10, 23, 27, 34, 41, 46, 49 (BATE's material; Syn.).

FAMILY PENAEIDAE

Fenneropenaeus indicus (H. Milne Edwards, 1837)

DISTRIBUTION. — Society (Tahiti) - *Aquaculture.*

REFERENCES. — ***Penaeus indicus*** - AQUACOP & PATROIS, 1990: 67 (Imported for aquaculture; see remark). — ***Fenneropenaeus indicus*** - PÉREZ FARFANTE & KENSLEY, 1997: 80, fig. 41 (New combination).

REMARK. — Several other penaeoid shrimps had been imported for aquaculture purposes in Tahiti: *Penaeus monodon*, *Litopenaeus stylirostris* and *L. vannamei.*

Funchalia taaningi Burkenroad, 1940

DISTRIBUTION. — Society (Huahine, Maiao, Tahiti) - *Pelagic (100-370m).*

REFERENCES. — ***Funchalia taaningi*** - NEW MATERIAL - Coll. ORSTOM/Tahiti, 1997, fish stomach and pelagic trawl, det. A. CROSNIER (Society, off Huahine, Maiao, Tahiti; MNHN Na13426-28; pelagic 100-370m).

Funchalia villosa (Bouvier, 1905)

DISTRIBUTION. — Society (Tahiti) - *Pelagic (50-700m).*

REFERENCES. — ***Funchalia villosa*** - NEW MATERIAL - Coll. ORSTOM/Tahiti, E. JOSSE, fish stomach, det. J. POUPIN & A. CROSNIER (Tahiti; MNHN Na13436).

Melicertus canaliculatus (Olivier, 1811)

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Penaeus canaliculatus*** - HELLER, 1865: 121 (Tahiti). — ***Penaeus (Melicertus) canaliculatus*** - HOLTHUIS, 1980: 47 (Catalogue). — ***Melicertus canaliculatus*** - PÉREZ FARFANTE & KENSLEY, 1997: 101 (New combination).

Metapenaeopsis commensalis Borradaile, 1898

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Metapenaeopsis commensalis*** - NEW MATERIAL - Coll. ORSTOM/Tahiti, P. FROUIN, det. A. CROSNIER (Tahiti; MNHN Na13430).

Metapenaeopsis difficilis Crosnier, 1991

DISTRIBUTION. — Marquesas (Tahuata) - *Sublittoral (64-79m).*

REFERENCES. — ***Metapenaeopsis difficilis*** Crosnier, 1991: 255, fig. 65-67 (Tahuata; 64-79m).

Metapenaeopsis hilarula (de Man, 1911)

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Metapenaeopsis hilarula*** - CROSNIER, 1991: 227, fig. 42-44, 45a-d, 46 (Tahiti).

Metapenaeopsis marquesas **Crosnier, 1991**

DISTRIBUTION. — Marquesas (Hiva Oa, Nuku Hiva, Tahuata, Ua Pou) - *Sublittoral (45-80m).*

REFERENCES. — ***Metapenaeopsis marquesas*** Crosnier, 1991: 244, fig. 57-59 (Hiva Oa, Nuku Hiva, Tahuata, Ua Pou; 45-80m).

Metapenaeopsis tarawensis **Racek & Dall, 1965**

DISTRIBUTION. — Society (Tahiti); Tuamotu (Marutea).

REFERENCES. — ***Metapenaeopsis tarawensis*** - CROSNIER, 1991: 241, fig. 54-56 (Marutea) - NEW MATERIAL - Coll. B. THOMASSIN & P. FROUIN, det. A. CROSNIER (Tahiti; MNHN Na13431-32).

Metapenaeopsis velutina **(Dana, 1852)**

DISTRIBUTION. — Pitcairn (neighbourhood of Gambier Islands) - *Deep (113-124m).*

REFERENCES. — ***Metapenaeopsis velutina*** - CROSNIER, 1991: 247, fig. 60-61 (Pitcairn; 113-124m).

Pelagopenaeus balboe **(Faxon, 1893)**

DISTRIBUTION. — Society (Maiao) - *Pelagic.*

REFERENCES. — ***Pelagopenaeus balboe*** - NEW MATERIAL - Coll. ORSTOM Tahiti 1997, fish stomach, det. A. CROSNIER (Society off Maiao; MNHN Na13425).

Penaeus monodon **Fabricius, 1798**

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Penaeus tahitensis*** Heller, 1862: 528; 1865: 121, pl. 11, fig. 2 (Tahiti). — ***Penaeus (Penaeus) monodon*** - HOLTHUIS, 1980: 50 (Syn.).

FAMILY SOLENOCERIDAE

Hadropenaeus lucasii **Bate, 1881**

DISTRIBUTION. — Tuamotu (Hao) - *Deep (522m).*

REFERENCES. — ***Hadropenaeus lucasii*** - NEW MATERIAL - Coll. RV *Marara*, det. A. CROSNIER (Hao; MNHN Na13435; 522m).

Haliporus curvirostris **Bate, 1881**

DISTRIBUTION. — Austral - *Deep (4346-4365m).*

REFERENCES. — ***Haliporus curvirostris*** - BATE, 1888: 288, pl. 42, fig. 1 (North of Tubuai, *Challenger*, st. 281, 6/10/1875, 22°21'S, 150°17'W, 4365 m; Southeast off Marotiri, st. 285, 14/10/1875, 32°36'S, 137°43'W, 4346m). — CROSNIER, 1988a: 567, fig. 1a-b, 2a, f, 3a, 4, 5, 6a-c, 9a, 10a-b, 11a-c (BATE's material, st. 285).

Hymenopenaeus halli **Bruce, 1966**

DISTRIBUTION. — Tuamotu (Moruroa) - *Deep (715m).*

REFERENCES. — ***Hymenopenaeus halli*** - POUPIN, 1996b: 4, pl. 1c (Moruroa; MNHN Na13434; 715m).

FAMILY SICYONIIDAE

DISTRIBUTION. — Marquesas (Hatutu, Motu One) - *Deep (416-460m).*

REFERENCES. — ***Sicyonia*** sp. - NEW MATERIAL - Coll. RV *Alis* Marquesas Expedition, det. A. CROSNIER, to be included in a revision of the family (Hatutu, Motu One; 416-460m).

FAMILY LUCIFERIDAE

Only two Luciferidae are reported with certainty from French Polynesia, *Lucifer chacei* Bowan and *L. typus* H. Milne Edwards. A third species, *Lucifer pacificus* Dana, has been described from the surroundings of Rangiroa, Tuamotu (15°20' S, 148° W; see DANA, 1852: 673; 1855, pl. 45, fig. 2). This material is no more extant and with DANA's description alone the species is "completely unrecognizable" (*cf.* HANSEN, 1919: 49).

Lucifer chacei Bowman, 1967

DISTRIBUTION. — Society (Bora Bora, Moorea, Tahiti); Tuamotu (Moruroa, Nukutipipi, Takapoto, Tikehau) - *Planktonic*.

REFERENCES. — ***Lucifer chacei*** - BOWMAN, 1967: 266, fig. 1-4 (Bora Bora, Moorea, Tahiti, Tikehau). — RENON, 1977: 223 (Takapoto); 1985: 391 (List of French Polynesian zooplankton); 1989: 78 (Syn.). — MERSCHARDT-SALVAT, 1991: 80, tab. K (Nukutipipi; larvae in the lagon). — ***Lucifer sp.*** - MICHEL, 1969: 122, tab. 5 (Moruroa).

Lucifer typus H. Milne Edwards, 1837

DISTRIBUTION. — Gambier (Mangareva); Society (Tahiti) - *Planktonic*.

REFERENCES. — ***Lucifer reynaudii*** - BATE, 1888: 466 (Tahiti). — ***Lucifer batei*** Borradaile, 1915: 228 (BATE's material). — ***Lucifer typus*** - NOBILI, 1907: 352, pl. 1, fig. 1 (Mangareva). — HANSEN, 1919: 49 (Syn.) - SYNONYM - *Lucifer batei* Borradaile, 1915 (*Lucifer reynaudii* H. Milne Edwards, 1837 is a species *Incertae sedis*, see HANSEN, 1919: 49 "...the name *L. Reynaudii* ought to be dropped").

FAMILY SERGESTIDAE

Sergia bigemmea (Burkenroad, 1940)

DISTRIBUTION. — Society ("off Tahiti") - *Bathypelagic*.

REFERENCES. — ***Sergia bigemmea*** - PÉREZ-FARFANTE & KENSLEY, 1997: 199 ("off Tahiti").

REMARK. — World-wide distributed sergestids shrimps are limited here to this single record although undoubtebly better represented in the area. *Sergestes fermerinkii* Bate, 1888 recorded in the surroundings of Raevavae (BATE, 1888: 419, pl. 76, fig. 4, *Challenger*, 24°S, 148°W) is a species *Incertae sedis*. HANSEN (1903: 67) when revising the *Sergestes* from the *Challenger* Expedition writes about it: "BATE has examined one specimen, captured in the 'Pacific Ocean, lat. 24°S, long. 148° W,' and measuring 5 mm. The specimen is not to be found in the Museum collection [MNH]. According to the figure it is a very young *Mastigopus* belonging either to *S. diapontius* Bate, H.J.H., or to a closely-allied species of the same group."

INFRA-ORDER STENOPODIDEA

The very common *Stenopus hispidus* (Olivier, 1811) is the single species regularly reported from the area. SENDLER (1923: 46) also reports an undetermined species of the genus *Stenopusculus* (juvenile from Makatea, Tuamotu; det. DE MAN). Therefore, in addition to the *Stenopus* sp. nov. listed hereafter, three more Stenopodidae have been recognised during the recent RV *Alis* Marquesas Expedition (J. POUPIN field notes; material not studied, deposited in MNHN collections).

FAMILY STENOPODIDAE

Stenopus hispidus (Olivier, 1811)

DISTRIBUTION. — Society (Tahiti); Tuamotu (Hao, Makatea, Raraka, Raroia).

REFERENCES. — ***Stenopus hispidus*** - DANA, 1852: 607; 1855, pl. 40, fig. 8 (Raraka). — NOBILI, 1907: 366 (Hao). — SENDLER, 1923: 45 (Makatea). — HOLTHUIS, 1953a: 60 (Raroia). — MORRISON, 1954: 13 (Raroia). — SALVAT, 1986a: 23 (Text); 1986b: 71, photograph (French Polynesia). — BAGNIS & CHRISTIAN, 1983: 109, photograph (Tuamotu). — ***Stenopus*** - PARDON, 1992: 81, photograph (Tahiti; according to the photograph, must be *S. hispidus*). — ***Stenopus*** ? - CHABOUIS L. & F., 1954: pl. 44 (French Polynesia).

***Stenopus* sp. nov.** (GOY in study)

DISTRIBUTION. — Tuamotu (Fangataufa) - *Deep (190m).*
REFERENCES. — ***Stenopus*** sp. nov. - POUPIN, 1996b: 4, pl. 1d (Fangataufa, 190m; in study with J. GOY).

INFRA-ORDER CARIDEA

Caridea have been first reported from French Polynesia by the 19th century voyages: the French 'Corvette' *La Coquille* (GUÉRIN-MENEVILLE, 1838), the American *US Exploring Expedition* (DANA, 1852, 1855), the American *North Pacific Expedition* (STIMPSON, 1860), the Austrian frigate *Novara* (HELLER, 1862, 1865), and the British *Challenger* (BATE, 1881, 1888). Through the activities of the J.C. GODEFFROY & SON shipping compagny, Polynesian shrimps were also deposited at the Museum GODEFFROY (1860-1886, HAMBURG; see historical by FRANSEN *et al.*, 1997), and subsequently purchased by the LEIDEN Museum (HOLTHUIS, 1950: 175) and the STRASBOURG Museum (ORTMANN, 1890, 1891).

Between 1902-1905, G. SEURAT, head of a Zoological laboratory established at Rikitea, Gambier Islands, sent several collections to Paris Museum. These were studied by NOBILI (1906, 1907). A succession of expeditions were then conducted in the Polynesian waters, with reports of more freshwater and lagoon shrimps: the Hanseatischen Südsee-Expedition (SENDLER, 1923); the Pacific Entomological Survey (ADAMSON, 1935); the Yacht *Alva* world cruise (BOONE, 1935); the Mangarevan Expedition of the Bernice P. BISHOP Museum (EDMONSON, 1935, 1944), and the Raroia Atoll Pacific Science Board Expedition (HOLTHUIS, 1953a; MORRISSON, 1954).

The alpheids have mainly been studied by BANNER & BANNER (1967), from a field trip made in 1954 in the Society Islands. Unfortunately all the material was destroyed in the Hawaii laboratory fire of 1961 (BANNER & BANNER, 1962). As a result BANNER & BANNER (1967) work is based on a draft manuscript and field notes, without any drawings. It is amazing to realise that type material of *Alpheus gracilipes* Stimpson, 1860, described from Tahiti, was destroyed in the Great Chicago fire of 1871 (MANNING, 1993a) and that, 90 years later, the neotype of that species, selected by BANNER & BANNER (1967) was again destroyed in the Hawaii laboratory fire.

In 1965, installation of a French nuclear base at Moruroa had generated several ecological surveys with occasional collections of shrimps. For example, *Periclimenaeus tuamotae* Bruce, 1969a was collected in 1965 in Moruroa by B. SALVAT. Later, these collections were pursued during the campaigns of the RV *Marara* (coll. B. RICHER DE FORGES, J.L. CARSIN, and J. POUPIN) mainly with deep pandalid shrimps (CROSNIER, 1986a,b, 1988b; CHAN & CROSNIER, 1991, 1997) but also with littoral component of the fauna, such as *Cinetorhynchus hendersoni* (Kemp, 1925) (OKUNO, 1997). Part of this material (13 species) is hereafter reported for the first time: *Nematocarcinus gracilis* Bate, 1888; *Janicella spinicauda* (A. Milne Edwards, 1883), *Stylodactylus* aff. *libratus* Filhol, 1885, *Anchistus demani* Kemp, 1922, *Harpiliopsis spinigera* (Ortmann, 1890), *Jocaste japonica* (Ortmann, 1890), *Paranchistus serenei* Bruce, 1983, *Periclimenes elegans* (Paulson, 1875), *Periclimenes grandis* (Stimpson, 1860), *Periclimenes mahei* Bruce, 1969a, *Philarius gerlachei* (Nobili, 1905), *Vir* sp. nov. Bruce (in preparation), and *Thor amboinensis* (De Man, 1888). Through ORSTOM Tahiti center activity (coll. E. JOSSE and P. FROUIN), four other shrimps are also added to the French Polynesian fauna: *Acanthephyra smithi* Kemp, 1939, *Oplophorus gracilirostris* A. Milne Edwards, 1881, *Salmoneus* ? *serratidigitus* (Coutière, 1896), *Nikoides* aff. *danae* Paulson, 1875, and *Processa* aff. *moana* Yaldwyn, 1971.

Since 1971, several ecological studies have been initiated by the French École Pratique des Hautes Études research center, now denominated CRIOBE and located at Moorea, Society Islands. These studies mainly report coral or algae associated shrimps (NAIM, 1980, identifications by HOLTHUIS; ODINETZ, 1983, identifications by BRUCE for the Palaemonidae, and BANNER for the Alpheidae; and KROPP & BIRKELAND, 1981) and freshwater shrimps (MARQUET, 1988, 1991, 1993, identifications by HOLTHUIS). The freshwater species are still currently under study (see KEITH & VIGNEUX, 1997).

FAMILY NEMATOCARCINIDAE

Nematocarcinus gracilis Bate, 1888

Distribution. — Tuamotu (Fangataufa, Marutea South) - *Deep (840-1000m).*

References. — ***Nematocarcinus gracilis*** - New material - Coll. RV *Marara*, det. T. Komai (Fangataufa, Marutea South; 840-1000m).

Nematocarcinus undulatipes Bate, 1888

Distribution. — Marquesas (Fatu Hiva); Society (Raiatea) - *Deep (570-850m).*

References. — ***Nematocarcinus undulatipes*** - Poupin, 1996b: 4, pl. 1e (Fatu Hiva, Raiatea; 570-850m).

FAMILY ATYIDAE

Atyoida pilipes (Newport, 1847)

Distribution. — Austral (Rurutu, Tubuai); Gambier (Mangareva); Marquesas (Eiao, Fatu Hiva, Hiva Oa, Nuku Hiva, Ua Huka, Ua Pou); Society (Moorea, Tahiti) - *Freshwater.*

References. — ***Atyoida tahitensis*** Stimpson, 1860: 28 [97] (Tahiti). — ***Atya brevirostris*** - Seurat, 1934: 50 (Tahiti). — Ricard, 1986: 88 (French Polynesia). — ***Atyoida serrata*** - Adamson, 1935: 16 (Eiao, Fatu Hiva, Hiva Oa, Nuku Hiva, Ua Pou). — Edmonson, 1935: 14 (Mangareva, Rapa, Tahiti; Marquesas) - Both not *Atyoida serrata* (Bate, 1888). — ***Ortmannia alluaudi*** - Adamson, 1935: 16 (Eiao, Fatu Hiva). — ***Vanderbiltia rosamondae*** Boone, 1935: 160, pl. 41-42 (Tahiti). — Holthuis, 1953b: 113, fig. 1 (Tahiti; redescription of Boone's material as a juvenile stage of *Atya serrata*; not *A. serrata* Bate, 1888, in Chace, 1983); 1980: 70 (Syn.). — ***Atyoida pilipes*** - Chace, 1983: 10, fig. 3-8 (Marquesas, Tahiti; Syn.). — Marquet, 1988: 87, fig. 48, tab. 23; 1991: 129, tab. 1 & 2; 1993: tab. 1 & 3 (Hiva Oa, Mangareva, Moorea, Nuku Hiva, Rurutu, Tahiti, Tubuai, Ua Huka, Ua Pou). — Mosseron, 1994: 4, fig. 3a (Nuku Hiva). — Mosseron & Fossati, 1994: 16, fig. 8a (Nuku Hiva). — Poupin, 1994: 5, fig. 1, pl. 1a (Tahiti). — Keith & Vigneux, 1997: 22, tab. 2 (Same Islands than Marquet) - Synonyms - *Atya brevirostris* De Man, 1892; *Ortmannia alluaudi* Bouvier, 1905.

Atyopsis spinipes (Newport, 1847) (doubtful)

Distribution. — Gambier (Mangareva) - *Freshwater.*

References. — ***Atya spinipes*** - Nobili, 1907: 353 ("Gatavake" = Mangareva). — Seurat, 1934: 51 ("Gatavake" = Mangareva). — ***Atyopsis spinipes*** - Chace, 1983: 35, figs 20-22 (Syn.; *cf.* remark).

Remark. — Chace (1983: 40) writes "Verification is also needed of the Magareva record in Nobili (1907) and Seurat (1934) in order to eliminate the possibility of confusion between *Atyopsis spinipes* and *Atyoida pilipes*, which seems to be established on the Gambier Islands". To confirm Chace's hesitations we remark that recent prospections in the Gambier rivers (electric fishing by Marquet: 1988, 1991, 1993) have brought only *Atyoida pilipes* and never *Atyopsis spinipes.*

Caridina rapaensis Edmonson, 1935

Distribution. — Austral (Rapa, Rurutu) - *Freshwater.*

References. — ***Caridina rapaensis*** Edmonson, 1935: 12 (Rapa). — Eldredge, 1967: 12 (Rapa; catalog). — Marquet, 1988: 87, fig. 48, tab. 23 ; 1991: 130, tab. 1 & 2 ; 1993: tab. 1 & 3 (Rurutu). — Keith & Vigneux, 1997: 24, tab. 2 (Marquet's data).

Caridina serratirostris De Man, 1892

Distribution. — Austral (Tubuai); Society (Moorea) - *Freshwater.*

REFERENCES. — ***Caridina serratirostris*** - MARQUET, 1988: 87, fig. 48, tab. 23 ; 1991: 130, tab. 1 & 2 ; 1993: tab. 1 & 3 (Moorea, Tubuai). — KEITH & VIGNEUX, 1997: 23, tab. 2 (Same Islands than MARQUET).

Caridina weberi De Man, 1892

DISTRIBUTION. — Austral (Rurutu, Tubuai); Marquesas (Fatu Hiva, Hiva Oa, Nuku Hiva, Ua Huka, Ua Pou); Society (Moorea, Tahiti) - *Freshwater.*

REFERENCES. — ***Caridina weberi*** - ADAMSON, 1935: 16 (Fatu Hiva, Nuku Hiva, Ua Pou). — EDMONSON, 1935: 10 (Tahiti, Marquesas). — MARQUET, 1988: 87, fig. 48, tab. 23; 1991: 129, tab. 1 & 2; 1993: tab. 1 & 3 (Hiva Oa, Moorea, Nuku Hiva, Rurutu, Tahiti, Tubuai, Ua Huka, Ua Pou). — MOSSERON, 1994: 4, fig. 3a (Nuku Hiva). — MOSSERON & FOSSATI, 1994: 16, fig. 8b-c (Nuku Hiva). — KEITH & VIGNEUX, 1997: 22, tab. 2 (Same Islands than MARQUET).

FAMILY OPLOPHORIDAE

Acanthephyra eximia Smith, 1884

DISTRIBUTION. — Austral (Tubuai); Tuamotu (Fangataufa, Hao, Moruroa) - *Bathypelagic (720-1050m).*

REFERENCES. — ***Acanthephyra eximia*** - POUPIN *et al.*, 1990: 15 (French Polynesia). — POUPIN, 1996b: 4, pl. 1e (Fangataufa, Hao, Moruroa; 720-1050m) - NEW MATERIAL - Coll. Y. PLESSIS, 14/05/79, det. A. CROSNIER (Paris, MNHN Na7259; Tubuai; 800m).

Acanthephyra smithi Kemp, 1939

DISTRIBUTION. — French Polynesia - *Bathypelagic (Up to 3450m).*

REFERENCES. — ***Acanthephyra smithi*** - NEW MATERIAL - Coll. E. JOSSE 1995, fish stomach, det. J. POUPIN, material deposited at ORSTOM/Tahiti (French Polynesia, probably between Society and Marquesas).

Acanthephyra stylorostratis (Bate, 1888)

DISTRIBUTION. — Austral - *Bathypelagic (4346m).*

REFERENCES. — ***Bentheocaris exuens*** Bate, 1888: 724, pl. 123-fig. 3 (Southeast off Marotiri, *Challenger*, st. 285, 14/10/1875, 32°36'S, 137°43'W, 4346m). — ***Acanthephyra stylorostrata*** - CHACE, 1940: 144, fig. 22 (Syn.; see remark).

REMARK. — CHACE writes "It is very probable that BATE's *Bentheocaris exuens* is the same species [than *A. stylorostratis*] but, inasmuch as CALMAN states that the type is in such condition that comparison is almost impossible and as BATE's figure is inadequate its seems best to retain the much more suitable name, *stylorostrata*, for this form."

Heterogenys microphthalma (Smith, 1885)

DISTRIBUTION. — Austral - *Bathypelagic (4346m).*

REFERENCES. — ***Acanthephyra longidens*** Bate, 1888: 735, pl. 124-fig. 4 (Southeast off Marotiri, *Challenger*, st. 285, 14/10/1875, 32°36'S, 137°43'W, 4346m). — ***Heterogenys microphthalma*** - CHACE, 1986: 38, fig. 20 (Syn.).

Janicella spinicauda (A. Milne Edwards, 1883)

DISTRIBUTION. — Probably Tuamotu (Moruroa) - *Bathypelagic (500m?).*

REFERENCES. — ***Janicella spinicauda*** - NEW MATERIAL - Coll. Y. PLESSIS & B. RICHER DE FORGES, det. A. CROSNIER (Paris, MNHN Na7255, no location but probably Moruroa according to number given by the collector).

Oplophorus gracilirostris A. Milne Edwards, 1881

DISTRIBUTION. — Society (Maiao); Tuamotu (Mataiva) - *Bathypelagic (100-370m).*

REFERENCES. — ***Oplophorus gracilirostris*** - NEW MATERIAL - Coll. ORSTOM 1997, fish stomach and pelagic trawl, det. A. CROSNIER (Off Mataiva and Maiao; MNHN Na13429; bathypelagic 100-370m).

Oplophorus spinosus (Brullé, 1839)

DISTRIBUTION. — Tuamotu (Fangataufa) - *Bathypelagic (30-100m).*

REFERENCES. — ***Oplophorus spinosus*** - POUPIN, 1996b: 4, pl. 1g (Fangataufa; in plankton net 30-100m).

Oplophorus typus Milne Edwards, 1837

DISTRIBUTION. — Marquesas (Nuku Hiva, Tahuata) - *Bathypelagic (541-580m).*

REFERENCES. — ***Oplophorus typus*** - POUPIN *et al.*, 1990: 15 (French Polynesia). — POUPIN, 1996b: 4, pl. 1h (Nuku Hiva, Tahuata; 541-580m).

Systellaspis debilis (A. Milne Edwards, 1881)

DISTRIBUTION. — Tuamotu (Fangataufa) - *Bathypelagic (50-100m).*

REFERENCES. — ***Systellaspis debilis*** - POUPIN, 1996b: 6, pl. 2a (Fangataufa; in plankton net 50-100m).

Systellaspis pellucida Filhol, 1885

DISTRIBUTION. — Tuamotu (Hao) - *Bathypelagic (1020m).*

REFERENCES. — ***Systellaspis pellucida*** - POUPIN, 1996b: 6, pl. 2b (Hao; 1020m).

FAMILY STYLODACTYLIDAE

Stylodactylus aff. *libratus* Chace, 1983

DISTRIBUTION. — Tuamotu (Moruroa) - *Deep (512m).*

REFERENCES. — ***Stylodactylus* aff. *libratus*** - NEW MATERIAL - Coll. J. POUPIN, det. R. CLEVA (MNHN Na 13400; Moruroa; 512m).

FAMILY RHYNCHOCINETIDAE

Cinetorhynchus hendersoni (Kemp, 1925)

DISTRIBUTION. — Austral (Rapa).

REFERENCES. — ***Cinetorhynchus hendersoni*** - OKUNO, 1997: 46, fig. 9, 12d-f, pl. 1f (Comb. nov.; Rapa).

Cinetorhynchus hiatti (Holthuis & Hayashi, 1967)

DISTRIBUTION. — Marquesas (Nuku Hiva); Tuamotu (Raroia).

REFERENCES. — ***Rhynchocinctes hiatti*** n. sp. - HOLTHUIS, 1953a: 54 (Raroia; *nomina nuda*). — MORRISON, 1954: 18 (Same material). — ***Rhynchocinetes hiatti*** Holthuis & Hayashi, 1967: 162, fig. 1-2 (Raroia; holotype from Formosa). — FRANSEN *et al.*, 1997: 14 (Paratypes RMNH D8939; Raroia). — ***Cinetorhynchus hiatti*** - OKUNO, 1997: 40, fig. 5, pl. 1c (Comb. nov.; Nuku Hiva).

Cinetorhynchus reticulatus Okuno, 1997

DISTRIBUTION. — Marquesas (Nuku Hiva).

REFERENCES. — ***Cinetorhynchus reticulatus*** Okuno, 1997: 49, fig. 10-11, 12a-c, pl. 1g, h (Nuku Hiva).

FAMILY GNATHOPHYLLIDAE

Gnathophyllum americanum Guerin, 1856

DISTRIBUTION. — Gambier (Mangareva); Society (Tahiti); Tuamotu (Raroia) - *Free-living or coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Gnathophyllum pallidum*** Ortmann, 1890: 537 (Tahiti). — ***Gnathophyllum tridens*** Nobili, 1906: 259; 1907: 365, pl. 1, fig. 4 ("Rikitea" = Mangareva). — ***Gnathophyllum americanum*** - BOONE, 1935: 197, pl. 54 (Tahiti; Syn.). — HOLTHUIS, 1949: 210 (NOBILI's material; Syn.); 1953a: 60 (Raroia). — ODINETZ, 1983: 207 (Tahiti; in coral *Pocillopora*, non obligate associate).

FAMILY ANCHISTIOIDIDAE

Anchistioides compressus **Paulson, 1875**

DISTRIBUTION. — Gambier (Mangareva) - ? *Sponge associate.*

REFERENCES. — ***Amphipalaemon seurati*** Nobili, 1906: 259; 1907: 364, pl. 1, fig. 3 ("Tearia" = Mangareva; 22m). — SEURAT, 1934: 51, 60 ("Gatavake" = Mangareva; in Freshwater, see remark). — ***Anchistioides compressus*** - BRUCE, 1967: 570 (NOBILI's material).

REMARK. — *Anchistoides* species are common in a variety of sponge and, on occasion, in tunicate; freshwater record of SEURAT is certainly erroneous (A.J. BRUCE, personal communication).

FAMILY HYMENOCERIDAE

Hymenocera picta **Dana, 1852**

DISTRIBUTION. — Tuamotu (Raraka) - ? *Echinoderm associate.*

REFERENCES. — ***Hymenocera picta*** Dana, 1852: 593; 1855, pl. 39, fig. 3a-c (Raraka; "Coral reef" without mention of echinoderm host).— BRUCE, 1982: 209 (Possibly an echinoderm associate). — CHACE & BRUCE, 1993: 137 (Syn.).

FAMILY PALAEMONIDAE

SUB-FAMILY PALAEMONINAE

Brachycarpus biunguiculatus **(Lucas 1846)**

DISTRIBUTION. — Tuamotu (Raroia).

REFERENCES. — ***Brachycarpus biunguiculatus*** - HOLTHUIS, 1953a: 55 (Raroia). — MORRISON, 1954: 18 (Raroia).

Macrobrachium aemulum **(Nobili, 1906)**

DISTRIBUTION. — Austral (Rurutu, Tubuai); Gambier (Mangareva); Society (Moorea, Tahiti) - *Freshwater.*

REFERENCES. — ***Palaemon (Parapalaemon) aemulus*** Nobili, 1906: 258; 1907: 362, pl. 1, fig. 5 ("Gatavake" = Mangareva; elevation 180m). — SEURAT, 1934: 51 ("Gatavake" = Mangareva). — ***Macrobrachium aemulum*** - HOLTHUIS, 1953a: 54 (Tahiti). — MARQUET, 1988: 90, fig. 48, tab. 23; 1991: 135, tab. 1 & 2; 1993: tab. 1 & 3 (Mangareva, Moorea, Rurutu, Tahiti, Tubuai). — KEITH & VIGNEUX, 1997: 22, tab. 2 (Same Islands than MARQUET).

Macrobrachium australe **(Guérin-Méneville, 1838)**

DISTRIBUTION. — Austral (Rurutu, Tubuai); Gambier (Mangareva); Marquesas (Fatu Hiva, Hiva Oa, Nuku Hiva, Ua Huka, Ua Pou); Society (Moorea, Tahiti) - *Freshwater.*

REFERENCES. — ***Palaemon australis*** Guérin-Méneville, 1838: 37 (Tahiti). — ***Palaemon dispar*** - ADAMSON, 1935: 17 (Fatu Hiva, Hiva Oa, Ua Pou). — ***Palaemon (Eupalaemon) dispar*** - NOBILI, 1907: 361 (Tahiti). — SEURAT, 1934: 50 (Tahiti). — ***Macrobrachium australe*** - HOLTHUIS, 1950: 124, fig. 27-30 (Tahiti); 1953a: 55 (Tahiti); 1980: 87 (Syn.). — GRAND, 1986: 84, fig. 2-3 (French Polynesia). — RICARD, 1986: 88 (French Polynesia). — MARQUET, 1988: 87, fig. 48, tab. 23; 1991: 133, tab. 1 & 2; 1993: tab. 1 & 3 (Hiva Oa, Mangareva, Moorea, Nuku Hiva, Rurutu, Tahiti, Tubuai, Ua Huka, Ua Pou). — DANIGO, 1991: 5, fig. 8, pl. 1a (Nuku Hiva). — FOUILLAND, 1993: 10, fig. 6 (Nuku Hiva). — KEITH & VIGNEUX, 1997: 22, tab. 2 (Same Islands than MARQUET) - SYNONYM - *Palaemon dispar* von Martens, 1868.

Macrobrachium lar **(Fabricius, 1798)**

DISTRIBUTION. — Austral (Rurutu, Tubuai); Gambier (Mangareva); Marquesas (Eiao, Fatu Hiva, Hiva Oa, Nuku Hiva, Tahuata, Ua Huka, Ua Pou); Society (Moorea, Tahiti) - *Freshwater.*

REFERENCES. — ***Palaemon spectabilis*** Heller, 1862: 527; 1865: 113, pl. 10, fig. 8 (Tahiti). — ***Palaemon vagus*** Heller, 1865: 113 (Tahiti). — ***Bithynis lar*** - BATE, 1888: 789, pl. 124-fig. 1 (Tahiti). — ***Palaemon lar*** - ADAMSON, 1935: 17 (Eaio, Fatu Hiva, Hiva Oa, Nuku Hiva, Tahuata, Ua Huka, Ua Pou). — ***Palaemon (Eupalaemon) lar*** - DE MAN, 1904: 291, pl. 18, fig. 1 (Tahiti). — NOBILI, 1907: 361 (Tahiti). — SEURAT, 1934: 50 (Tahiti). — BOONE, 1935: 150, pl. 38 (Tahiti). — ***Macrobrachium lar*** - HOLTHUIS, 1950: 176, fig. 37; 1980: 96 (Syn.). — GRAND, 1986: 84, fig. 1 (French Polynesia). — RICARD, 1986: 88, photograph (French Polynesia). —

MARQUET, 1988: 87, fig. 48, tab. 23; 1991: 134, tab. 1 & 2; 1993: tab. 1 & 3 (Hiva Oa, Mangareva, Moorea, Nuku Hiva, Rurutu, Tahiti, Tubuai, Ua Huka, Ua Pou). — DANIGO, 1991: 5, fig. 8, pl. 1b (Nuku Hiva). — FOUILLAND, 1993: 10, fig. 6 (Nuku Hiva). — CHACE & BRUCE: 1993: 20 (Key). — KEITH & VIGNEUX, 1997: 22, tab. 2 (Same Islands than MARQUET).

Macrobrachium latimanus (von Martens, 1868)

DISTRIBUTION. — Austral (Rurutu, Tubuai); Gambier (Mangareva); Marquesas (Fatu Hiva, Hiva Oa, Motane, Nuku Hiva, Ua Huka, Ua Pou); Society (Moorea, Tahiti) - *Freshwater.*

REFERENCES. — ***Palaemon latimanus*** - ORTMANN, 1890: 737, pl. 47, fig. 11, 11z (Tahiti). — ADAMSON, 1935: 17 (Fatu Hiva, Hiva Oa, "Mohotani" = Motane, Ua Pou). — ***Macrobranchium latimanus*** - HOLTHUIS, 1980: 97 (Syn). — GRAND, 1986: 84-85, fig. 4 (French Polynesia). — RICARD, 1986: 88 (French Polynesia). — MARQUET, 1988: 90, fig. 48, tab. 23; 1991: 134, tab. 1 & 2; 1993: tab. 1 & 3 (Hiva Oa, Mangareva, Moorea, Nuku Hiva, Rurutu, Tahiti, Tubuai, Ua Huka, Ua Pou). — DANIGO, 1991: 5, fig. 6, 8, pl. 1c (Nuku Hiva). — CHACE & BRUCE: 1993: 20 (Key). — FOUILLAND, 1993: 10, fig. 6 (Nuku Hiva). — KEITH & VIGNEUX, 1997: 22, tab. 2 (Same Islands than MARQUET) - RELEVANT MATERIAL - ***Macrobrachium* sp. nov.** - MNHN Na 1251, Na 1379, coll. Père Simon DELMAS, 4/7/1926, det. J. SHORT; MNHN Na 14404, coll. M. de TRÉVIÈRE 1937, det. J. SHORT (Moorea) - ***Macrobrachium* sp. 1 & 2** - KEITH & VIGNEUX, 1997: 11, 22, tab. 2 (*Macrobrachium* sp. 1, Hiva Oa, Moorea, Nuku Hiva, Tahiti, Ua Huka, Ua Pou; *Macrobrachium* sp. 2, Moorea, Tahiti).

REMARK. — In Paris collections, J. SHORT has recognised a new species, related to *Macrobrachium latimanus*. This species, denominated *Onana* in Polynesian language, is currently under study.

Arbitrarily we place here the *Macrobrachium* sp. 1 and sp. 2. mentioned by KEITH & VIGNEUX (1997). According to these authors (personal communication), HOLTHUIS think that they could belong to two new species. SHORT study should bring some clarification on that point.

Macrobrachium lepidactyloïdes (De Man, 1892)

DISTRIBUTION. — Marquesas (Hiva Oa, Nuku Hiva, Ua Huka, Ua Pou); Society (Moorea) - *Freshwater.*

REFERENCES. — ***Macrobrachium*** sp. - MARQUET, 1988: 90, fig. 48, tab. 23; 1991: 135, tab. 1 & 2; 1993: tab. 1 & 3 (Hiva Oa, Moorea, Nuku Hiva, Ua Huka, Ua Pou). — DANIGO, 1991: 5, fig. 8 (Nuku Hiva). — ***Macrobrachium lepidactyloïdes*** - CHACE & BRUCE: 1993: 20 (Key). — SHORT, in prepartion (Syn., personal communication).

Macrobrachium rosenbergii (de Man, 1879)

DISTRIBUTION. — Society (Tahiti) - *Freshwater, aquaculture.*

REFERENCES. — ***Macrobrachium rosenbergii*** - GRAND, 1986: 85, photograph (French Polynesia). — PARDON, 1992: 116, photograph (Tahiti). — CHACE & BRUCE: 1993: 20, 36, fig. 15 (Syn. & key). — AQUACOP & PATROIS, 1990: 67 (Aquaculture).

Palaemon concinnus Dana, 1852

DISTRIBUTION. — Austral (Rurutu, Tubuai); Society (Moorea, Tahiti); Tuamotu (Makatea) - *Brackish water.*

REFERENCES. — ***Leander concinnus*** - SENDLER, 1923: 46 (Makatea). — ***Palaemon concinnus*** - HOLTHUIS, 1950: 61, fig. 12 (Tahiti); 1953a: 54 (Tahiti); 1980 (Syn.). — MARQUET, 1988: 90, fig. 48, tab. 23; 1991: 136, tab. 1 & 2; 1993: tab. 1 & 3 (Moorea, Rurutu, Tahiti, Tubuai; "estuaries and shallow stagnant waters"). — CHACE & BRUCE: 1993: 40 (Syn. & key). — KEITH & VIGNEUX, 1997: 22, tab. 2 (Same Islands than MARQUET).

Palaemon debilis Dana, 1852

DISTRIBUTION. — Austral (Tubuai); Gambier (Mangareva); Tuamotu (Hao, Rangiroa, Raroia) - *Brackish water.*

REFERENCES. — ***Leander debilis*** - NOBILI, 1907: 363 (Hao, "Rikitea" = Mangareva). — ***Periclimenes Leander debilis*** - SEURAT, 1934: 60 (Hao, "Rikitea" = Mangareva). — ***Palaemon debilis*** - HOLTHUIS, 1953a: 54 (Raroia). — MORRISON, 1954: 5 (Raroia). — MARQUET, 1988: 90, fig. 48, tab. 23; 1991: 136, tab. 1 & 2; 1993: tab. 1 & 3 (Mangareva, Rangiroa, Tubuai; "estuaries and shallow stagnant waters"). — CHACE & BRUCE: 1993: 40 (Syn. & key). — KEITH & VIGNEUX, 1997: 22, tab. 2 (Same Islands than MARQUET).

SUB-FAMILY PONTONIINAE

Anchiopontonia hurii (Holthuis, 1981)

DISTRIBUTION. — Tuamotu (Raroia) - *Bivalve associate (Gen.* Spondylus*).*

REFERENCES. — ***Pontonia hurii*** n. sp. - HOLTHUIS, 1953a: 57 (Raroia; *nomina nuda*). — MORRISON, 1954: 6 (Same material; commensal in the spiny oyster *Spondylus varius*). — ***Pontonia hurii*** Holthuis, 1981: 796, fig. 4

(Paratype from Raroia). — ***Anchiopontonia hurii*** - BRUCE, 1992a: 1276, fig. 1-4 (Comb. nov.). — Fransen *et al.*, 1997: 15 (Paratypes RMNH D9248; Raroia).

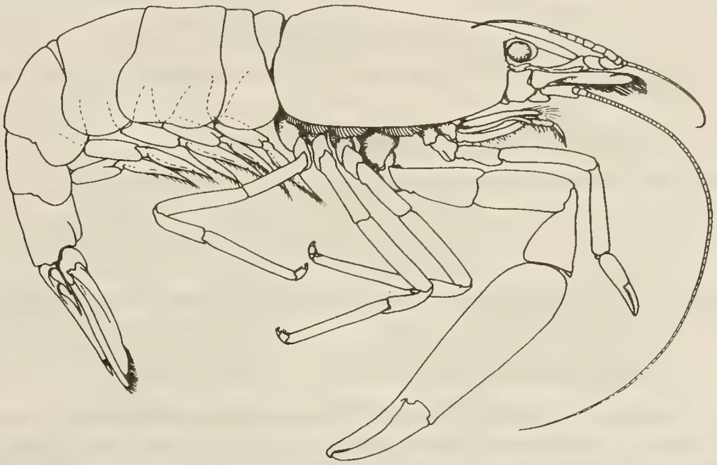

Figure 2 - *Anchiopontonia hurii* (Holthuis, 1981)
(From BRUCE, 1992a)

Anchistus demani Kemp, 1922

DISTRIBUTION. — Tuamotu (Moruroa) - *Bivalve associate (Gen.* Tridacna).

REFERENCES. — ***Anchistus demani*** - NEW MATERIAL - Coll. J. POUPIN April-May 1997, det. A.J. BRUCE (Moruroa MNHN Na13416; in bivalve *Tridacna maxima*).

Anchistus miersi (De Man, 1888)

DISTRIBUTION. — Gambier (Mangareva) - *Bivalve associate (Gen.* Pinctada*)*.

REFERENCES. — ***Anchistus miersi*** - NOBILI, 1907: 359 ("Mangareva-Tearia" = Mangareva). — SEURAT, 1934: 60 (Gambier; in pearl oyster *Pinctada margaritifera*). — CHACE & BRUCE, 1993: 71, 72 (Syn. & key). — FRANSEN, 1994: 89, pl. 1d (Photograph).

Conchodytes meleagrinae Peters, 1852

DISTRIBUTION. — Gambier (Mangareva); Tuamotu (Amanu, Raroia) - *Bivalve associate (Gen.* Pinctada*)*.

REFERENCES. — ***Conchodytes meleagrinae*** - NOBILI, 1907: 359 (Mangareva). — SEURAT, 1934: 60 (Gambier, Tuamotu; in pearl oyster *Pinctada margaritifera*). — HOLTHUIS, 1953a: 59 (Amanu, Raroia). — BRUCE, 1989a: 184 (Key). — CHACE & BRUCE, 1993: 74 (Syn.). — FRANSEN, 1994: 96, fig. 21, pl. 1e (Photograph).

Conchodytes ? *tridacnae* Peters, 1852

DISTRIBUTION. — Tuamotu (Fangataufa) - *Bivalve associate (Gen.* Pinctada*)*.

REFERENCES. — ***Conchodytes tridacnae*** - BRUCE, 1989a: 184 (Key) - NEW MATERIAL - Coll. J. POUPIN April-May 1997, det. A.J. BRUCE, with a ? (Fangataufa MNHN Na13415; in pearl oyster *Pinctada margaritifera*).

Coralliocaris graminea (Dana, 1852)

DISTRIBUTION. — Society (Moorea, Tahiti); Tuamotu (Takapoto) - *Coral associate (Gen.* Pocillopora*)*.

REFERENCES. — ***Coralliocaris graminea*** - ODINETZ, 1983: 205 (Moorea, Tahiti, Takapoto; in coral *Pocillopora*). — ODINETZ-COLLART & RICHER DE FORGES, 1985: 201 (Same material). — CHACE & BRUCE, 1993: 77 (Syn. & key). — BRUCE, in preparation (Host genera *Acropora*, rarely *Pocillopora*, *Seriatopora*, *Stylophora*).

Coralliocaris nudirostris (Heller, 1861)

DISTRIBUTION. — Society (Tahiti) - *Coral associate (Gen.* Acropora*)*.

REFERENCES. — ***Coralliocaris tahitoei*** Boone, 1935: 180, pl. 49 (Tahiti without mention of association). — ***Coralliocaris nudirostris*** - CHACE & BRUCE, 1993: 47 (Syn.). — BRUCE, in preparation (Host genus *Acropora*).

Coralliocaris superba (Dana, 1852)

DISTRIBUTION. — Society (Raiatea, Tahiti); Tuamotu (Fangataufa, Moruroa) - *Coral associate (Gen.* Acropora*).*

REFERENCES. — ***Coralliocaris superba*** - STIMPSON, 1860: 40 [107] (Tahiti; "in coralliis"). — BOONE, 1935: 170, pl. 46 (Raiatea, Tahiti; "in coral"). — CHACE & BRUCE, 1993: 76, 77 (Syn. & key) - NEW MATERIAL - Coll. J. POUPIN April/May 1996 & April-May, 1997, det. A.J. BRUCE (Fangataufa MNHN Na13409, Moruroa; in coral *Acropora*).

Coralliocaris viridis Bruce, 1974

DISTRIBUTION. — Society (Tahiti); Tuamotu (Fangataufa) - *Free-living or coral associate (Gen.* Acropora, Pocillopora*).*

REFERENCES. — ***Coralliocaris viridis*** - ODINETZ, 1983: 207 (Tahiti; in coral *Pocillopora*, non obligate associate). — NEW MATERIAL - Coll. J. POUPIN April-May 1997, det. A.J. BRUCE (Fangataufa MNHN Na13412; in coral *Acropora*).

REMARK. — In ODINETZ (1983) this species is reported as "*Gnathocaris* ? *viridis* Bruce", but it is correctly recorded under *Coralliocaris viridis* in Paris MNHN (Na6625).

Exoclimenella denticulata (Nobili, 1906)

DISTRIBUTION. — Gambier (Mangareva); Tuamotu (Raroia) - *Free-living or coral associate (Gen.* Acropora*).*

REFERENCES. — ***Periclimenes petithouarsi*** var. ***denticulata*** Nobili, 1906: 257; 1907: 358 ("Gatavake" = Mangareva). — ***Palaemonella denticulata*** - HOLTHUIS, 1953a: 55 (Raroia; in coral *Acropora*). — MORRISON, 1954: 5 (Raroia). — ***Periclimenes denticulatus*** - BRUCE, 1992b: 59, fig. 12-14 (Syn.; "32m, trap, on sand with *Halimeda*"). — ***Exoclimenella denticulata*** - ĎURIŠ & BRUCE, 1995: 637, fig. 9-11 ("Gatavake" = Mangareva, Raroia; new combination and this remark "free-living browser, and only incidentaly associated with coral"). — BRUCE, in preparation (Host genus: *Acropora*).

Fennera chacei Holthuis, 1951

DISTRIBUTION. — Society (Moorea); Tuamotu (Takapoto) - *Coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Fennera chacei*** - KROPP & BIRKELAND, 1981: 629, tab. 5 (Moorea, Takapoto; in coral *Pocillopora*). — BRUCE, in preparation (Host genera: *Pocillopora, Porites, Stylophora*).

Harpiliopsis beaupresii (Audouin, 1825)

DISTRIBUTION. — Society (Moorea, Tahiti); Tuamotu (Fangataufa, Moruroa, Takapoto) - *Coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Harpiliopsis beaupressi*** - KROPP & BIRKELAND, 1981: 629, tab. 5 (Moorea, Takapoto; in coral *Pocillopora*). — ODINETZ, 1983: 205 (Moorea, Tahiti, Takapoto; in coral *Pocillopora*). — ODINETZ-COLLART & RICHER DE FORGES, 1985: 201 (Same material). — CHACE & BRUCE, 1993: 82 (Syn. & key). — BRUCE, in preparation (Host genera: *Pocillopora, Seriatophora, Stylophora*, rarely *Acropora*) - NEW MATERIAL - Coll. J. POUPIN April/May 1996 and April-May 1997 det. A.J. BRUCE (Fangataufa MNHN Na13402-13413, Moruroa MNHN Na13403; in coral *Pocillopora*).

Harpiliopsis depressa (Stimpson, 1860)

DISTRIBUTION. — Marquesas (Fatu Hiva, Hiva Oa); Society (Moorea, Tahiti); Tuamotu (Moruroa, Takapoto) - *Coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Harpiliopsis depressus*** - KROPP & BIRKELAND, 1981: 629, tab. 5 (Moorea, Takapoto; in coral *Pocillopora*). — ODINETZ, 1983: 205 (Moorea, Tahiti, Takapoto; in coral *Pocillopora*). — ***Harpiliopsis depressa*** - CHACE & BRUCE, 1993: 82 (Syn. & key). — BRUCE, in preparation (Host genera: *Pocillopora, Seriatopora, Stylophora*, rarely *Acropora, Porites*) - NEW MATERIAL - Coll. J. POUPIN, February 1996 & April-May, 1997, det. A.J. BRUCE (Fatu Hiva, Hiva Oa, Moruroa MNHN Na13406; in coral *Pocillopora*).

Harpiliopsis spinigera (Ortmann, 1890)

DISTRIBUTION. — Marquesas (Hiva Oa); Tuamotu (Fangataufa, Moruroa) - *Coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Harpiliopsis spinigera*** - CHACE & BRUCE, 1993: 82 (Syn. & key). — FRANSEN, 1994: 108, fig. 60, 62, pl. 2b (Syn.). — BRUCE, in preparation (Host genera: *Pocillopora, Stylophora*) - NEW MATERIAL - Coll. J. POUPIN October 1995, February 1996, and April-May, 1997, det. A.J. BRUCE (Fangataufa MNHN Na13401, Hiva Oa, Moruroa; in coral *Pocillopora*).

Jocaste japonica (Ortmann, 1890)

DISTRIBUTION. — Tuamotu (Fangataufa) - *Coral associate (Gen.* Acropora*).*

REFERENCES. — ***Jocaste japonica*** - BRUCE, 1969b: 300, fig. 1 (Host genera: *Acropora*, rarely *Pocillopora*); in preparation (Host genus: *Acropora*). — NEW MATERIAL - Coll. J. POUPIN April-May 1997, det. A.J. BRUCE (Fangataufa MNHN Na13411; in coral *Acropora*).

Jocaste lucina (Nobili, 1901)

DISTRIBUTION. — Society (Tahiti); Tuamotu (Fangataufa, Moruroa) - *Coral associate (Gen.* Acropora*)*.

REFERENCES. — ***Coralliocaris lamellirostris*** - BOONE, 1935: 174, pl. 47 (Tahiti). — ***Jocaste lucina*** - CHACE & BRUCE, 1993: 49, 84 (Syn. & key; BOONE's reference with a ?). — BRUCE, in preparation (Host genera: *Acropora*, rarely *Pocillopora, Stylophora*) - NEW MATERIAL - Coll. J. POUPIN April-May 1996 & April-May 1997, det. A.J. BRUCE (Fangataufa MNHN Na13410, Moruroa) - SYNONYM - ***Coralliocaris lamellirostris*** Stimpson, 1860.

Onycocaris quadratophthalma (Balss, 1921)

DISTRIBUTION. — Society (Tahiti) - *Free-living or coral associate (Gen.* Pocillopora*)*.

REFERENCES. — ***Onycocaris quadratophthalma*** - CASTRO, 1971: 396 (Host *Toxadocia violacea*, Porifera, Demospongia). — ODINETZ 1983: 207 (Tahiti; in coral *Pocillopora*, non obligate associate).

Palaemonella lata Kemp, 1922

DISTRIBUTION. — Society (Tahiti) - *Free-living or coral associate (Gen.* Pocillopora*)*.

REFERENCES. — ***Palaemonella lata*** - BRUCE, 1970: 274 (Key). — ODINETZ, 1983: 207 (Tahiti; in coral *Pocillopora*, non obligate associate). — NEW MATERIAL - Coll. P. FROUIN 1993/1994, det. A.J. BRUCE (FROUIN st. n°1030, Tahiti).

Palaemonella rotumana (Borradaile, 1898)

DISTRIBUTION. — Society (Moorea) - *Free-living, coral , or sea-weed associate.*

REFERENCES. — ***Palaemonella rotumana*** - BRUCE, 1970: 274 (Key); 1976b: table 8 ("Society & Marquesas"; BRUCE personal communication: location must be a table entry error). — NAIM, 1980, annex 1-2 (Moorea; in filamentous sea-weed *Giffordia mitchellae*). — CHACE & BRUCE, 1993: 87, 89 (Syn. & key). — FRANSEN, 1994: 117 (Syn.; "Free-living and occuring among corals").

Palaemonella tenuipes Dana, 1852

DISTRIBUTION. — Society (Moorea, Tahiti); Tuamotu (Takapoto) - *Free-living or coral associate (Gen.* Pocillopora*)*.

REFERENCES. — ***Palaemonella tenuipes*** - BRUCE, 1970: 274 (Key). — NAIM, 1980, annex 1, tab. 3 (Moorea). — ODINETZ, 1983: 207 (Moorea, Tahiti, Takapoto; in coral *Pocillopora*, non obligate associate). — ODINETZ-COLLART & RICHER DE FORGES, 1985: 201 (Same material). — CHACE & BRUCE: 1993: 87, 89 (Syn. & key).

Paranchistus serenei Bruce, 1983

DISTRIBUTION. — Tuamotu (Fangataufa) - *Bivalve associate (Gen.* Pinctada*)*.

REFERENCES. — ***Paranchistus serenei*** - NEW MATERIAL - Coll. J. POUPIN, February 1996, det. A.J. BRUCE (Fangataufa, in pearl oyster *Pinctada margaritifera*, 10m; MNHN Na13352) - RELEVANT NEW MATERIAL - ? ***Paranchistus*** sp. - Coll. J. POUPIN April-May 1997, det. A.J. BRUCE (Fangataufa; in pearl oyster *Pinctada margaritifera*).

Periclimenaeus cf. *tridentatus* (Miers, 1884)

DISTRIBUTION. — Society (Moorea) - *Sea-weed associate (Gen.* Halimeda*)*.

REFERENCES. — ***Periclimenaeus tridentatus*** - NAIM, 1980, annex 1-2 (Moorea; in sea-weed *Halimeda opuntia*). — CHACE & BRUCE: 1993: 92, 93 (Syn. & key). — ***Periclimenaeus cf. tridentatus*** - BRUCE personal communication (*cf.* remark).

REMARK. — According to BRUCE, personal communication: "I did get hold of the NAIM *Periclimenaeus tridentatus* spms from Leiden and in my opinion they were definitely not that species. They could be new. I made some drawings and then unfortunately lost the best specimen! ... What I would like is some more specimens."

Periclimenaeus tuamotae Bruce, 1969a

DISTRIBUTION. — Tuamotu (Moruroa).

REFERENCES. — ***Periclimenaeus tuamotae*** Bruce, 1969a: 170 (Moruroa). — CHACE & BRUCE, 1993: 54 (List).

Periclimenella spinifera (de Man, 1902)

DISTRIBUTION. — Society (Moorea, Tahiti); Tuamotu (Takapoto) - *Free-living or coral associate (Gen.* Pocillopora*)*.

REFERENCES. — ***Anchistia inaequimana*** - HELLER, 1865: 109 (Tahiti). — ***Periclimenes (Harpilius) spiniferus*** - HOLTHUIS, 1952: 76, fig. 30 (Syn.). — ***Periclimenes spiniferus*** - ODINETZ, 1983: 207 (Moorea, Tahiti, Takapoto; non obligate coral *Pocillopora* associate). — ODINETZ-COLLART & RICHER DE FORGES, 1985: 201 (Moorea, Tahiti, Takapoto; in coral *Pocillopora*). — ***Periclimenella spinifera*** - DURIS & BRUCE, 1995: 656, fig. 19-20 (New combination; free-living, and associated with corals of the genera *Acropora*, *Millepora*, *Pavona*, *Pocillopora*, *Porites* and *Seriatopora*, or with a hydroid *Millepora tenera*). — BRUCE, in preparation (Host genera: various) - SYNONYM - ? *Anchistia inaequimana* Heller.

Periclimenes elegans **(Paulson, 1875)**

DISTRIBUTION. — Society (Tahiti); Tuamotu (Moruroa) - *Free-living or coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Periclimenes elegans*** - BRUCE, 1983: 884, 898 (Free-living shrimp). — NEW MATERIAL - Coll. O. ODINETZ, 1982, det. A.J. BRUCE 10/12/82, (Tahiti MNHN Na6618; in coral *Pocillopora damicornis* and *P. elegans*) - RELEVANT MATERIAL - Coll. J. POUPIN April-May 1997, det. A.J. BRUCE with a ? (Moruroa MNHN Na13408; in *Pocillopora*).

Periclimenes ensifrons **(Dana, 1852)**

DISTRIBUTION. — Tuamotu (Amanu, Fakahina) - *Free-living.*

REFERENCES. — ***Periclimenes ensifrons*** - NOBILI, 1907: 359 (Amanu, Fakahina). — CHACE & BRUCE, 1993: 95, 111 (Syn. & key).

Periclimenes grandis **(Stimpson, 1860)**

DISTRIBUTION. — Tuamotu (Fangataufa, Moruroa) - *Coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Periclimenes grandis*** - NEW MATERIAL - Coll. J. POUPIN April-May 1997, det. A.J. BRUCE (Fangataufa MNHN Na13414, Moruroa MNHN Na13407; in coral *Pocillopora*). — FRANSEN, 1994: 151 ("Free-living") - RELEVANT MATERIAL - ? ***Anchistia danae*** Stimpson, 1860: 41 [108] (Tahiti; *cf.* remark).

REMARK. — Concerning *Anchistia danae* Stimpson, BRUCE, personal communication, has the following remark: "The type material of STIMPSON's species is long gone and I do not think that the question of this species can now ever be resolved. It probably is a *Periclimenes*, at least. It is probably a well known species under some other name, possibly one of the *P. grandis* group (KEMP, 1922: 138). It lacked both second pereiopods and the ambulatory pereiopods, so is not really worth wasting further time on. The sooner it is completely forgotten the better..."

Periclimenes lutescens **(Dana, 1852)** (doubtful)

DISTRIBUTION. — Marquesas (Nuku Hiva); Society (Tahiti) - *Coral associate (Gen.* Acropora*).*

REFERENCES. — ***Harpilius lutescens*** - BOONE, 1935: 167, pl. 45 (Nuku Hiva, Tahiti). — ***Periclimenes lutescens*** - BRUCE, 1976a: 6 ("The species has been confused with *P. consobrinus* De Man, and some records need to be checked"); 1976b: 98 ("The records from Samoa, Tahiti and the Marquesas islands are in particular need of confirmation"); in preparation (Host genera: *Acropora*, rarely *Pocillopora*, *Seriatopora*). — CHACE & BRUCE, 1993: 94, 117 (Syn. & key).

Periclimenes madreporae **Bruce, 1969a**

DISTRIBUTION. — Society (Moorea, Tahiti); Tuamotu (Takapoto) - *Coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Periclimenes madreporae*** - ODINETZ, 1983: 205 (Moorea, Tahiti, Takapoto; in coral *Pocillopora*). — BRUCE, in preparation (Host genera: *Acropora*, *Pocillopora*, *Seriatopora*, *Stylophora*, *Turbinaria*).

Periclimenes mahei **Bruce, 1969a**

DISTRIBUTION. — Tuamotu (Fangataufa) - *Coral associate (Gen.* Acropora*).*

REFERENCES. — ***Periclimenes mahei*** - BRUCE, in preparation (Host genera: *Acropora*, *Pocillopora*, *Seriatopora*) - NEW MATERIAL - Coll. J. POUPIN, February 1996, det. A.J. BRUCE (Fangataufa; in coral *Acropora*, 10m).

Periclimenes poupini **Bruce, 1989**

DISTRIBUTION. — Austral (Maria, Rapa, Rurutu, Tubuai); Gambier; Society (Bora Bora); Tuamotu (Fangataufa, Moruroa) - *Ascidian associate; deep (409-600m).*

REFERENCES. — ***Periclimenes poupini*** Bruce, 1989b: 852, fig. 1-5, 6a (Bora Bora, Fangataufa, Gambier, Maria, Moruroa, Rapa, Rurutu, Tubuai; 409-600m). — POUPIN, 1996b: 6, pl. 2c (Same material). — ***Periclimenes* sp. nov.** - POUPIN *et al.*, 1990: 16 (French Polynesia). — POUPIN & RICHER DE FORGES, 1991: 211 (French Polynesia).

REMARK. — Lives on a the sea-anemone carried on the shell occupied by a parapagurid, *Sympagurus dofleini* (Balss, 1912).

Periclimenes soror Nobili, 1904

DISTRIBUTION. — Society (Tahiti); Tuamotu (Moruroa) - *Echinoderm associate (Genus* Culcita*)*.

REFERENCES. — ***Periclimenes soror*** - BRUCE, 1978: 299, fig. 1-6 (Moruroa, Tahiti); 1982: 200 (Asteroids hosts genera: *Choriaster, Culcita, Pentaceraster, Protoreaster, Acanthaster, Mithrodia, Echinaster*). — CHACE & BRUCE, 1993: 95, 122 (Syn. & key). — FRANSEN, 1994: 129, pl. 3f (Photograph) - NEW MATERIAL - Coll. J. POUPIN, det. A.J. BRUCE (Moruroa; on a sea star, *Culcita* ? *novaeguineae*).

Philarius gerlachei (Nobili, 1905)

DISTRIBUTION. — Tuamotu (Moruroa) - *Coral associate (Gen.* Acropora*)*.

REFERENCES. — ***Philarius gerlachei*** - NEW MATERIAL - Coll. J. POUPIN April/May 1996, det. A.J. BRUCE (Morura; in coral *Acropora* -10m; specimens with A.J. BRUCE).

Pontonides unciger Calman, 1939

DISTRIBUTION. — Marquesas (Tahuata) - *Coral associate (*Anthipataria*)*.

REFERENCES. — ***Pontonides unciger*** - MONOD, 1979: 10, fig. 9-35 (Tahuata; associated with a coral Anthipataria). — FRANSEN, 1994: 136, pl. 4d (Photograph; Anthipataria associate).

Stegopontonia commensalis Nobili, 1906

DISTRIBUTION. — Tuamotu (Hao, Raroia) - *Echinoderm associate (Gen.* Echinothrix*)*.

REFERENCES. — ***Stegopontonia commensalis*** Nobili, 1906: 258; 1907: 360, pl. 1, fig. 2 (Hao). — SEURAT, 1934: 60 (Commensal of sea urchin *Echinotrix turcarum*). — HOLTHUIS, 1953a: 58 (Raroia; commensal of *Echinothrix diadema*). — MORRISON, 1954: 6 (Raroia). — BRUCE, 1982: 204 (Echinoid hosts genera: *Diadema* and *Echinothrix*).

Vir sp. nov. Bruce (in preparation)

DISTRIBUTION. — Tuamotu (Moruroa) - *Coral associate (Gen.* Pocillopora*)*.

REFERENCES. — ***Vir* sp. nov.** - BRUCE in preparation (Moruroa, coll. J. POUPIN, February 1996, April/May 1997; in coral *Pocillopora*, 10m).

FAMILY ALPHEIDAE

Alpheopsis diabolus Banner, 1956

DISTRIBUTION. — Society (Bora Bora, Tahiti) - *Free-living or coral associate (Gen.* Pocillopora*)*.

REFERENCES. — ***Alpheopsis diabolus*** - BANNER & BANNER, 1967: 262 ("BD8, BD22" = Bora Bora). — ODINETZ, 1983: 208 (Tahiti; in coral *Pocillopora*, non obligate associate). — CHACE, 1988: 5 (Syn.).

Alpheopsis equalis Coutière, 1896

DISTRIBUTION. — Society (Bora Bora, Tahiti).

REFERENCES. — ***Alpheopsis equalis*** - BANNER & BANNER, 1967: 262 ("BD3-4, BD6, BD30" = Tahiti, "BD9, BD13-14, BD18" = Bora Bora); 1983: 11 ("collected from reef flat to 150m").

Alpheus aculeipes var. *tryphopus* Nobili, 1906

DISTRIBUTION. — Tuamotu (Marokau).

REFERENCES. — ***Alpheus aculeipes* var. *tryphopus*** Nobili, 1906: 257; 1907: 355 (Marokau).

Alpheus amirantei sizou Banner & Banner, 1967

DISTRIBUTION. — Society (Bora Bora, Tahiti).

REFERENCES. — ***Alpheus amirantei sizou*** Banner & Banner, 1967: 265 (Bora Bora, Tahiti; outer reef platform). — MIYA, 1984: 91 (Collected in living or dead coral).

Alpheus bradypus Coutière, 1905a

DISTRIBUTION. — Society (Bora Bora).

REFERENCES. — ***Alpheus bradypus*** - BANNER & BANNER, 1967: 275 ("BD8" = Bora Bora, inner reef).

Alpheus bidens (Olivier, 1811)

DISTRIBUTION. — Tuamotu (Takapoto) - *Free-living or coral associate (Gen.* Pocillopora*).*

REFERENCES - ***Alpheus bidens*** - ODINETZ, 1983: 207 (Takapoto; in coral *Pocillopora*, non obligate associate).

Alpheus brevipes Stimpson, 1860

DISTRIBUTION. — Society (Moorea, Tahiti).

REFERENCES. — ***Alpheus brevipes*** - BANNER & BANNER, 1967: 274 ("BD2" = Tahiti, from various coral heads, "BD33" = Moorea, probably on the fringing reef).

Alpheus bucephalus Coutière, 1905a

DISTRIBUTION. — Society (Moorea); Tuamotu (Takapoto) - *Non obligate coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Alpheus bucephalus*** - KROPP & BIRKELAND, 1981: 630, tab. 5 (Moorea, Takapoto; in coral *Pocillopora*). — CHACE, 1988: 17 ("Intertidal to 80m").

Alpheus collumianus Stimpson, 1860

DISTRIBUTION. — Society (Bora Bora, Moorea, Tahiti); Tuamotu (Makatea, Marutea South, ?Takapoto) - *Free-living or coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Alpheus seurati*** Coutière 1905a: 881, pl. 75, fig. 20, 20a-e; 1905b: 22 (Marutea). — SEURAT, 1934: 60 (Marutea South). — ***Alpheus collumianus*** - NOBILI, 1907: 354 (Marutea South). — SENDLER, 1923: 46 (Makatea). — CHACE, 1988: 19 (Syn.). — MIYA, 1974: 109, pl. 19, fig. a-d (See remark); 1984: 92 (Under coral rock and among branches and in holes in bases of living *Acropora*). — ODINETZ, 1983: 207 (Tahiti, but recorded as "Takapoto" in Paris collections; in coral *Pocillopora*, non obligate associate). — BANNER & BANNER, 1983: 27 (Specimens found in association with a sea star, *Ophiothrix keystonia*) - RELEVANT MATERIAL - ***Alpheus collumianus medius*** - BANNER & BANNER, 1967: 264 ("BD3, BD30" = Tahiti, "BD8, BD22" = Bora Bora, "BD33" = Moorea). — MIYA, 1974: 112, pl. 16, fig. e-g (See remark). — ***Alpheus collumianus inermis*** - BANNER & BANNER, 1967: 264 ("BD2-3, BD5-6, BD30" = Tahiti, "BD16" = Bora Bora, "BD33" = Moorea; see remark). — ***Alpheus probabilis*** - ODINETZ, 1983: 207 (Moorea, Tahiti; in coral *Pocillopora*, non obligate associate; recorded under *A. collumianus probabilis* Banner, 1956, det. BANNER, in MNHN collections).

REMARK. — From material collected in the Marianas, BANNER (1956) has established three *collumianus* subspecies: *Alpheus collumianus probablis*, *A. c. medius*, and *A. c. inermis*. He supposed that *Alpheus collumianus probabilis* would probably be identical with STIMPSON's typical species but because of the distance from type locality (Bonin Islands) and the Marianas, and the lack of specimens from the Bonins he considered that "it was inadvisable to assume this (*A. c. probabilis*) to be exactly the same form as would be found there". This question remains still open (see MIYA, 1974) and the exact identity of these three subspecies must be clarified. For example, BANNER & BANNER (1967: 265) write: "According to field notes, a pair of cherry-red specimens apparently cohabiting were collected off southern Bora Bora and were bottled together as BD16. By the criteria established to separate the two subspecies, one appears to be *A. c. medius* and one *A. c. inermis*. Obviously this collection throws considerable doubt on the validity of the subspecies, but more specimens should be examined before the subspecies, distinct anatomically, are discarded".

Alpheus crockeri (Armstrong, 1941)

DISTRIBUTION. — Society (Bora Bora, Moorea, Tahiti).

REFERENCES. — ***Alpheus crockeri*** - BANNER & BANNER, 1966a: 159 (Syn.); 1967: 264 ("BD3" = Tahiti, from coral heads, "BD8, inner reef, BD12, mud and sandflats most specimens under rocks" = Bora Bora; Moorea). — MIYA, 1974: 124, pl. 21 (Syn.; living in dead coral head and on corallin algae).

Alpheus cythereus Banner & Banner, 1966b

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Alpheus cythereus*** Banner & Banner, 1966b: 125, fig. 45 (Tahiti; from head of dead coral); 1967: 282 (Tahiti).

Alpheus diadema Dana, 1852

DISTRIBUTION. — Gambier (Mangareva); Society (Bora Bora, Moorea, Tahiti) - *Free-living, coral (Gen.* Pocillopora*), or algae (Gen.* Actinotrichia, Halimeda, Hydroclathrus, Symploca, Turbinaria*) associate.*

REFERENCES. — ***Alpheus insignis*** - NOBILI, 1907: 355 (Mangareva). — ***Alpheus diadema*** - BANNER, 1956: 357 (Syn.). — BANNER & BANNER, 1967: 267 ("BD3, coral heads, BD37, inner reef" = Tahiti, "BD8, inner reef, BD13, barrier reef, BD21, sandy area from scattered heads of deads corals, BD26, BD28, from dead coral heads, behind growing reef" = Bora Bora). — MIYA, 1974: 152, pl. 29 (Syn.; collected in bases of coral *Pocillopora*, *Heliopora*, and *Porites*, or in coralline algal masses). — NAIM, 1980, annex 1-2 (Moorea; in algae *Hydroclathrus* *clathratus, Halimeda opuntia, Symploca hypnoides, Turbinaria ornata, Actinotrichia rigida*). — ODINETZ, 1983: 207 (Moorea, Tahiti; in coral *Pocillopora*, non obligate associate). — ODINETZ-COLLART & RICHER DE FORGES, 1985: 201 (Moorea, Tahiti; in coral *Pocillopora*) - SYNONYM - *Alpheus insignis* Heller, 1861

Alpheus dolerus Banner, 1956

DISTRIBUTION. — Society (Bora Bora, Moorea, Tahiti).

REFERENCES. — ***Alpheus dolerus*** - BANNER & BANNER, 1967: 283 ("BD4, reef flat" = Tahiti, "BD14, BD18, BD20, from massive dead heads of *Porites*" = Bora Bora,"BD33" = Moorea). — BANNER & BANNER, 1983: 126 (Sand with shells and corals, hard blocks).

Alpheus edamensis De Man, 1888

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Alpheus acanthomerus*** Ortmann, 1890: 474, pl. 36, fig. 12 (Tahiti). — ***Alpheus edamensis*** - BANNER & BANNER, 1966b: 157, fig. 61 (At low tide under rocks; "Society"). — MIYA, 1984: 92 (Under dead coral rocks in fine coral sands). — CHACE, 1988: 24 (Syn.; intertidal to 50m).

Alpheus edwardsii (Audouin, 1826)

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Alpheus edwardsii*** - ORTMANN, 1890: 470 (Tahiti). — CHACE, 1988: 25 (Syn.; intertidal under rocks to 25m) - RELEVANT MATERIAL - ***Alpheus* cf. *edwardsii*** - NAIM, 1980, annex 1-2 (Moorea; in algae *Turbinaria ornata, Giffordia mitchellae, Actinotrichia rigida*).

Alpheus frontalis H. Milne Edwards, 1837

DISTRIBUTION. — Society (Moorea, Tahiti); Tuamotu (Raroia) - *Under rocks in algal tube,* or *coral associate (Gen.* Pocillopora*)*.

REFERENCES. — ***Alpheus frontalis*** - HELLER, 1865: 107 (Tahiti). — ***Alpheus frontalis*** - BANNER, 1959: 141 ("Hamahomo" = Rairoa; in algal tube, under rocks). — MIYA, 1974: 135, pl. 23, fig. d-g ("Could be found living in pairs in tubes which they made from filamentous blue-green or dark brown algae (Gen. *Lyngbya*). These tubes were found branching and penetrating between the fronds of dead corals ..."). — BANNER & BANNER, 1983: 30 (Living in felted tubes of filamentous blue-green algae, genera *Plectonema, Lyngbya, Microcoleus*). — ODINETZ, 1983: 207 (Moorea - locality not indicated clearly in the work but mentioned in MNHN catalogue; in coral *Pocillopora*, non obligate associate). — CHACE, 1988: 28 (Syn.; "*Albatross* specimens were found swimming at the surface under an electric light").

Alpheus gracilipes Stimpson, 1860

DISTRIBUTION. — Marquesas; Society (Bora Bora, Moorea, Tahiti) - *In algae (Gen.* Halimeda, Symploca*) or coral (Gen.* Pocillopora*)*.

REFERENCES. — ***Alpheus gracillipes*** Stimpson, 1860: 32 [100] (Tahiti "inter corallia"). — HELLER, 1865: 108 (Tahiti). — ORTMANN, 1890: 488 (Marquises). — BANNER & BANNER, 1967: 276 ("BD3, coral heads, BD30, BD36, inner reef" = Tahiti, "BD7, shallow fringing reef, BD13, sandy bottom from various living and dead corals, BD14, BD19, from *Pocillopora*, BD21-22, BD25-26, BD28-29" = Bora Bora; Moorea; redescription). — MIYA, 1974: 154, pl. 30 (In dead and overgrown corals of *Pocillopora* spp., *Stylophora mordax* and others). — NAIM, 1980, annex 1-2 (Moorea; in algae *Halimeda opuntia* and *Symploca hypnoides*). — KROPP & BIRKELAND, 1981: 630, tab. 5 (Moorea; in coral *Pocillopora*). — ODINETZ, 1983: 207 (Moorea, Tahiti; in coral *Pocillopora*, non obligate associate).

Alpheus gracilis Heller, 1861

DISTRIBUTION. — Society (Bora Bora, Tahiti).

REFERENCES. — ***Alpheus gracilis simplex*** - BANNER & BANNER, 1967: 268 ("BD18, from consolidated reef flat made of massive heads of *Porites* sp." = Bora Bora, "BD30, from various heads of coral" = Tahiti). — ***Alpheus gracilis*** - MIYA, 1984: 94 (With dead corals). — CHACE, 1988: 30 (Syn.).

Alpheus hoplites Nobili, 1906

DISTRIBUTION. — Tuamotu (Marutea South).

REFERENCES. — ***Alpheus hoplites*** Nobili, 1906: 257; 1907: 357, pl. 1, fig. 7 (Tuamotu).

REMARK. — Since its description, *Alpheus hoplites* seems to have disappeared from the literature. Type specimen is however still in MNHN collections (Na 2508, 1 sp. in bad condition; coll. G. SEURAT Marutea South 1905, det. NOBILI).

Alpheus idiocheles Coutière, 1905a

DISTRIBUTION. — Society (Bora Bora, Moorea, Tahiti) - *Burrower.*

REFERENCES. — ***Alpheus idiocheles*** - BANNER & BANNER, 1967: 271 ("BD2, various coral head" = Tahiti, "BD9, outer ridge of coralline alga" = Bora Bora, "BD32, wave-washed ridge of calcareous alga" = Moorea; "specimens of *A. idiocheles* ...were found living in galleries").

Alpheus lobidens De Haan 1850

DISTRIBUTION. — Gambier (Mangareva); Society (Bora Bora, Maupiti, Moorea, Tahiti).

REFERENCES. — ***Alpheus lobidens*** - NOBILI, 1907: 356 (Mangareva). — BANNER & BANNER, 1983: 36 (Syn.). — ***Alpheus crassimanus*** - BANNER & BANNER, 1967: 283 ("BD1, under algal mat with small mussels, BD35, under coral heads" = Tahiti, "BD12, mud and sand flat, under rocks, BD24, from coral boulders, BD25, on a sand mud spit" = Bora Bora, "BD23" = Maupiti, "BD33" = Moorea) - SYNONYM - *Alpheus crassimanus* Heller, 1865.

Alpheus lottini Guérin-Méneville, 1829

DISTRIBUTION. — Society (Moorea, Raiatea, Tahiti); Tuamotu (Moruroa, Takapoto) - *Coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Alpheus laevis*** - HELLER, 1865: 107 (Tahiti). — ***Alpheus obesomanus*** - BOONE, 1935: 135 (Raiatea, Tahiti; in coral) "partim" *in* BANNER & BANNER, 1964, not *A. obesomanus* Dana, 1852. — ***Alpheus lottini*** - BANNER & BANNER, 1964: 88 (Syn.); 1967: 267 ("BD2, various coral head" = Tahiti, "BD15, from *Pocillopora*, BD26, living and dead coral" = Bora Bora; Moorea). — KROPP & BIRKELAND, 1981: 629, tab. 5 (Moorea, Takapoto; in coral *Pocillopora*). — ODINETZ, 1983: 205 (Moorea, Tahiti, Takapoto; in coral *Pocillopora*). — KIM & ABELE, 1988: 33, fig. 13 (Syn.; Exclusively in coral Pocilloporidae). — FRANSEN *et al.*, 1997: 154 (Dry collections RMNH D5544; Tahiti) - FIELD OBSERVATION - J. POUPIN, 1997 (Moruroa; in coral *Pocillopora*) - SYNONYM - *Alpheus laevis* Randall, 1839.

Alpheus malleodigitus (Bate, 1888)

DISTRIBUTION. — Society (Bora Bora, Moorea, Tahiti) - *Free-living or coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Alpheus malleodigitus*** - BANNER & BANNER, 1966a: 174 (Syn.); 1967: 270 ("BD3, from coral head, BD4, from reef flat, BD6, BD30, various heads of corals" = Tahiti, "BD8, BD13, from various living and dead coral, BD14, BD18, BD20, from massive dead heads of *Porites*, BD28-29, from dead coral heads" = Bora Bora, "BD33-34" = Moorea). — MIYA, 1974: 130, pl. 22 fig. f-g (Syn.; in holes of the basal part of living, overgrown and dead corals). — ODINETZ, 1983: 207 (Tahiti; in coral *Pocillopora*, non obligate associate).

Alpheus microscaphis (Banner, 1959)

DISTRIBUTION. — Society (Moorea).

REFERENCES. — ***Alpheus microscaphis*** - BANNER & BANNER, 1967: 273 ("BD32, wave-washed ridge of calcareous alga" = Moorea).

Alpheus mitis Dana, 1852 Incertae sedis

DISTRIBUTION. — Tuamotu (Fakahina, Makatea).

REFERENCES. — ***Alpheus mitis*** - NOBILI, 1907: 355 (Fakahina). — SENDLER, 1923: 46 (Makatea). — BANNER & BANNER, 1983: 55 (*cf.* remark).

REMARK. — BANNER & BANNER (1983: 55-57) write "There is a serious question in our minds about the separation of *A. paracritinus* and *A. mitis* Dana...Unfortunately we cannot reexamine the type specimens for that of DANA is missing...Therefore the question of the separation of the two species must at present be left unanswered..."

Alpheus nobili Banner & Banner, 1966a

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Alpheus nobili*** - BANNER & BANNER, 1967: 269 ("BD30, from various heads of coral" = Tahiti).

Alpheus oahuensis (Banner, 1953)

DISTRIBUTION. — Tuamotu (Takapoto) - *Free-living or coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Alpheus oahuensis*** - ODINETZ, 1983: 207 (Takapoto; in coral *Pocillopora*, non obligate associate).

Alpheus obesomanus Dana, 1852

DISTRIBUTION. — Society (Bora Bora, Moorea, Raiatea, Tahiti) - *Free-living or coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Alpheus obesomanus*** - BOONE, 1935: 135, pl. 35, in coral; "partim" *in* BANNER, & BANNER (1964: 88), (Raiatea, Tahiti). — BANNER & BANNER, 1966a: 174 (Syn.); 1967: 269 ("BD2-3, from coral heads, BD4, from reef flat, BD5, outer ridge encrusted with smooth coralline alga, BD30, various heads of coral, BD37" = Tahiti, "BD8-9, BD13, from various living and dead corals, BD14, BD19, from dead and overgrown heads of *Pocillopora* spp., BD20, from massive dead heads of *Porites*, BD21, from scattered heads of dead coral, BD26, fom living and dead coral" = Bora Bora, "BD32" = Moorea). — MIYA, 1974: 127, pl. 22, fig. a-e (Syn.). — ODINETZ, 1983: 207 (Tahiti, not indicated in work but mentioned in MNHN collections; in coral *Pocillopora*, non obligate associate).

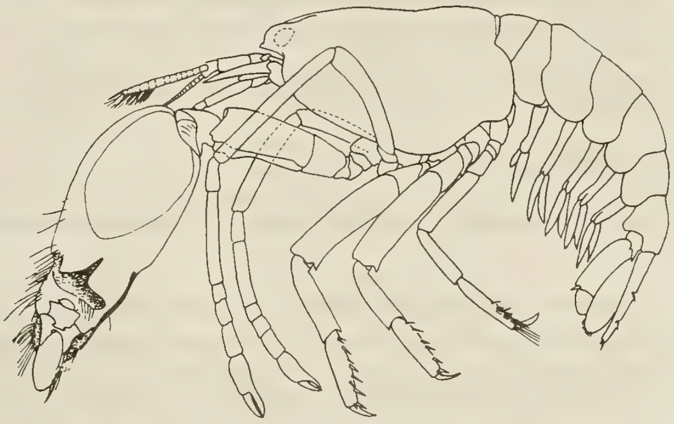

Figure 3 - *Alpheus obesomanus* Dana, 1852
(From MIYA, 1974)

Alpheus ovaliceps Coutière, 1905a

DISTRIBUTION. — Society (Bora Bora, Tahiti).

REFERENCES. — ***Alpheus ovaliceps*** - BANNER & BANNER, 1967: 275 ("BD3, from coral heads" = Tahiti, "BD8, from inner reef" = Bora Bora). — CHACE, 1988: 44 (Syn.).

Alpheus pachychirus Stimpson, 1860

DISTRIBUTION. — Society (Bora Bora, Moorea, Tahiti) - *Free-living or coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Alpheus pachychirus*** - DE MAN, 1890: 116, pl. 6, fig. 14 (Tahiti). — ORTMANN, 1890: 489, pl. 26, fig. 17a-k (Tahiti). — BANNER & BANNER, 1967: 275 ("BD7, BD13, from various living and dead corals, BD14, BD15, from *Pocillopora* spp., BD20, from massive dead heads of *Porites*, BD26, from living and dead coral" = Bora Bora; Moorea). — MIYA, 1974: 133, pl. 23, fig. a-c (Syn.). — ODINETZ, 1983: 207 (Moorea, Tahiti, Takapoto; in coral *Pocillopora*, non obligate associate).

Alpheus pacificus Dana, 1852

DISTRIBUTION. — Gambier (Mangareva); Society (Bora Bora, Moorea, Tahiti); Tuamotu (Taiaro).

REFERENCES. — ***Alpheus pacificus*** - NOBILI, 1907: 356 (Mangareva). — BANNER & BANNER, 1967: 283 ("BD8" = Bora Bora; Moorea). — KIM & ABELE, 1988: 100, fig. 42 (Syn.). — POUPIN, 1994: 6, fig. 2 (Mangareva, Tahiti, Taiaro; at low tide, sandy area, under rocks).

Alpheus paracritinus Miers, 1881

DISTRIBUTION. — Society (Bora Bora, Moorea, Tahiti); Tuamotu (Takapoto) - *Free-living or coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Alpheus paracritinus*** - BANNER & BANNER, 1967: 278 ("BD4, BD30, various heads of corals, BD36-37" = Tahiti, "BD11, from dead heads of *Porites*, BD13, various living and dead corals, BD21, scattered heads of dead corals, BD25, BD28, dead coral heads" = Bora Bora, "BD34" = Moorea). — MIYA, 1974: 157, pl. 31 (Syn.). — ODINETZ, 1983: 207 (Moorea, Tahiti, Takapoto; in coral *Pocillopora*, non obligate associate). — ODINETZ-COLLART & RICHER DE FORGES, 1985: 201 (Takapoto).

Alpheus paradentipes Coutière, 1905a

DISTRIBUTION. — Society (Tahiti); Tuamotu (Takapoto) - *Free-living or coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Alpheus paradentipes*** - ODINETZ, 1983: 207 (Tahiti, Takapoto; in coral *Pocillopora*, non obligate associate).

Alpheus parvirostris Dana, 1852

DISTRIBUTION. — Gambier (Mangareva); Society (Bora Bora, Moorea, Tahiti); Tuamotu (Marutea South, Takapoto) - *Free-living, coral associate (Gen.* Pocillopora*), or bivalve associate (Gen.* Pinctada*).*

REFERENCES. — ***Alpheus parvirostris*** - COUTIÈRE 1905b: 23 (Marutea). — NOBILI, 1907: 356 (Mangareva). — SEURAT, 1934: 60 (In pearl oyster *Pinctada margaritifera*). — BANNER & BANNER, 1967: 284 ("BD4, BD6, BD36-37" = Tahiti, "BD7-8, BD11, BD13-14, BD17, BD19-22, BD25-26, BD28-29" = Bora Bora, "BD33-34" = Moorea). — KROPP & BIRKELAND, 1981: 630, tab. 5 (Moorea, Takapoto). — ODINETZ, 1983: 207 (Moorea, Tahiti, Takapoto; in coral *Pocillopora*, non obligate associate). — CHACE, 1988: 47 (Syn.) - ***Alpheus euchiroides*** Nobili, 1906: 257; 1907: 356, pl. 1, fig. 6 (Marutea).

Alpheus perplexus Banner, 1956

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Alpheus perplexus*** - BANNER & BANNER, 1967: 270 ("BD30, from various heads of coral" = Tahiti).

Alpheus platyunguiculatus (Banner, 1953)

DISTRIBUTION. — Society (Bora Bora, Moorea, Tahiti) - *Free-living or coral associate (G.* Acropora*).*

REFERENCES. — ***Alpheus platyunguiculatus*** - BANNER & BANNER, 1967: 281 ("BD17, from partially living *Acropora* and coralline alga" = Bora Bora, "BD30, from various heads of coral" = Tahiti, "BD33" = Moorea).

Alpheus rostratipes Pocock, 1890

DISTRIBUTION. — Society (Bora Bora, Moorea, Tahiti).

REFERENCES. — ***Alpheus rostratipes*** - BANNER & BANNER, 1967: 268 ("BD2, BD30, BD38" = Tahiti, "BD8-9, BD14, BD17-18, BD22" = Bora Bora, "BD32" = Moorea).

Alpheus strenuus Dana, 1852

DISTRIBUTION. — Society (Bora Bora, Moorea, Tahiti); Tuamotu (Hao, Makatea, Takapoto) - *Free-living or coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Alpheus strenuus*** - ORTMANN, 1890: 475 (Tahiti) — NOBILI, 1907: 356 (Hao). — SENDLER, 1923: 46 (Makatea). — BANNER & BANNER, 1966a: 181 (Syn.); 1967: 284 ("BD12, mud and sand flats, most specimens under rocks" = Bora Bora; Moorea). — ODINETZ, 1983: 207 (Takapoto; in coral *Pocillopora*, non obligate associate). — CHACE, 1988 (Syn.).

Alpheus sublucanus (Forskål, 1775)

DISTRIBUTION. — Gambier (Mangareva); Marquesas (Nuku Hiva); Society (Moorea, Raiatea, Tahiti); Tuamotu (Makatea).

REFERENCES. — ***Alpheus ventrosus*** - NOBILI, 1907: 355 (Rikitea). — SENDLER, 1923: 46 (Makatea). — BOONE, 1935: 126, pl. 33 ("Anaho bay" = Nuku Hiva, "Point Venus" = Tahiti, "Teviatoa" = Raiatea). — ***Alpheus sublucanus*** - HOLTHUIS, 1980: 122 (Syn.). — NAIM, 1980, annex 1, tab. 3 (Moorea) - SYNONYM - *Alpheus ventrosus* H. Milne Edwards, 1837.

Alpheus sulcatus Kingsley, 1878

DISTRIBUTION. — Marquesas (Nuku Hiva); Society (Bora Bora, Moorea, Tahiti).

REFERENCES. — ***Alpheus macrochirus*** - ORTMANN, 1890: 485 (Tahiti). — BANNER & BANNER, 1967: 268 ("BD14, from ridge demarking outer margin of inner reef flat" = Bora Bora; Moorea; Nuku Hiva).— ***Alpheus sulcatus*** - BANNER & BANNER, 1985: 65 (Syn.) - SYNONYM - *Alpheus macrochirus* Richters, 1880.

Athanas areteformis Coutière, 1903

DISTRIBUTION. — Society.

REFERENCES. — ***Athanas areteformis*** - BANNER & BANNER, 1960: 138 (Syn.); 1967: 261 (Society). — CHACE, 1988: 61 (Syn.).

Athanas djiboutensis Coutière, 1897

DISTRIBUTION. — Gambier (Mangareva); Marquesas (Nuku Hiva); Society (Moorea, Tahiti); Tuamotu (Hikueru, Takapoto) - *Free-living or coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Athanas djiboutensis*** - NOBILI, 1907: 353 (Hikueru, "Rikitea" = Mangareva). — BOONE, 1935: 119, pl. 31. ("Anaho bay" = Nuku Hiva). — BANNER & BANNER, 1960: 140 (Tahiti); 1967: 261 (Society). — NAIM, 1980, annex 1, tab. 3 (Moorea). — ODINETZ, 1983: 208 (Moorea, Tahiti, Takapoto; in coral *Pocillopora*, non obligate associate). — ODINETZ-COLLART & RICHER DE FORGES, 1985: 201 (Moorea and/or Tahiti, Takapoto). — CHACE, 1988: 62 (Syn.) - RELEVANT MATERIAL - ***Athanas* cf. *djiboutensis*** - KROPP & BIRKELAND, 1981: 630, tab. 5 (Moorea).

Athanas dorsalis (Stimpson, 1860)

DISTRIBUTION. — Gambier (Mangareva); Tuamotu (Fakarava, Hao, Marutea South) - *Echinoid associate (Gen.* Heterocentrotus*).*

REFERENCES. — ***Arete dorsalis* var. *Pacificus*** - COUTIÈRE, 1904: 58 (Marutea South). — ***Arete maruteensis*** Coutière, 1905a: 864; 1905b: 18, fig. 1-6 (Marutea South; in sea urchin *Heterocentrotus mamillatus*). — NOBILI, 1907: 353 (Mangareva, Hao, Fakarava, Marutea). — SEURAT, 1934: 60 (Marutea South). — ***Athanas dorsalis*** - BANNER & BANNER, 1960: 151, fig. 5-6; 1967: 261 (Syn. and Tuamotu in distribution). — BRUCE, 1982: 207 (Echinoid hosts genera: *Centrostephanus*, *Echinothrix*, *Stomopneustes*, *Tripneustes*, *Heliocidaris*, *Centrostephanus*); 1990: 578 (Redescription with illustrations). — CHACE, 1988: 62 (Syn.).

Athanas gracilis Boone, 1935

DISTRIBUTION. — Society (Raiatea).

REFERENCES. — ***Athanas gracilis*** Boone, 1935: 122, pl. 32 (Raiatea). — BANNER & BANNER, 1960: 132 (List).

Athanas indicus (Coutière, 1903)

DISTRIBUTION. — Society (Bora Bora) - *Echinoid associate (Gen.* Echinometra*).*

REFERENCES. — ***Athanas indicus*** - BANNER & BANNER, 1960: 149 (Bora Bora); 1967: 260-261 (Society; "*Athanas indicus* was found living in exacavations made by the sea urchin *Echinometra*"). — BRUCE, 1982: 207 (Echinoid hosts genera: *Diadema*, *Echinometra*, *Anthocidaris*).

Athanas rhothionastes Banner & Banner, 1960

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Athanas rhothionastes*** Banner & Banner, 1960: 142, fig. 3 (Tahiti); 1967: 261 (Society).

Automate gardineri Coutière, 1902

DISTRIBUTION. — Society (Bora Bora, Moorea) - *Coral associate (Gen.* Acropora*).*

REFERENCES. — ***Automate gardineri*** - BANNER & BANNER, 1966a: 150 (Syn.); 1967: 261 ("BD17, from partially living *Acropora* and coralline alga" = Bora Bora, "BD33" = Moorea).

Metalpheus paragracilis (Coutière, 1897)

DISTRIBUTION. — Society (Bora Bora, Tahiti); Tuamotu (Marutea South) - *Free living or coral associate (Gen.* Acropora*).*

REFERENCES. — ***Alpheus paragracilis*** - COUTIÈRE 1905a: 883, pl. 76, fig. 22, 22a-g (Tahiti); 1905b: 23 (Marutea South). — SEURAT, 1934: 60 (Marutea South). — BANNER & BANNER, 1967: 268 ("BD6, barrier reef, BD30, from various coral heads, BD35, under coral heads on a gravel and sand expanse" = Tahiti, "BD8, inner reef, BD14, BD17, from partially living *Acropora* and coralline alga, BD18, from consolidated reef flat made mostly of massive heads of *Porites*, BD20, from massive dead heads of *Porites*" = Bora Bora). — ***Metalpheus paragracilis*** - BRUCE, 1976a: 44 (Syn.).

Salmoneus ? *serratidigitus* (Coutière, 1896)

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Salmoneus* ? *serratidigitus*** - NEW MATERIAL - Coll. P. FROUIN, det. A.J. BRUCE "to be checked by Y. MIYA" (st. FROUIN 1225, Tahiti; material with BRUCE).

Salmoneus sibogae (de Man, 1910) (presence uncertain)

DISTRIBUTION. — Society (?).

REFERENCES. — ***Salmoneus sibogae*** - BANNER & BANNER, 1964: 86 (Syn.); 1967: 261 ("Locality notes lost"; could be Society and/or Cook Islands).

Salmoneus tricristatus Banner, 1959

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Salmoneus tricristata*** - BANNER & BANNER, 1967: 262 ("BD30, from various heads of coral" = Tahiti). — ***Salmoneus tricristatus*** - MIYA, 1972: 43, pl. 5 (Syn.).

Synalpheus brachyceros Nobili, 1906

DISTRIBUTION. — Tuamotu (Makatea).

REFERENCES. — ***Synalpheus brachyceros*** Nobili, 1906: 256; 1907: 354, pl. 1, fig. 8 (Makatea). — de MAN, 1911: 190, 199 (List & key).

REMARK. — Species never retrieved since NOBILI's description.

Synalpheus charon (Heller, 1861)

DISTRIBUTION. — Society (Bora Bora, Moorea, Tahiti); Tuamotu (Takapoto) - *Free living or coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Synalpheus charon*** - BANNER & BANNER, 1967: 262 ("BD2, various coral heads" = Tahiti, "BD20, from massive dead heads of *Porites*" = Bora Bora). — MIYA, 1972: 51, pl. 8 (Syn.). — BRUCE, 1976a: 48 (Coral host, genus *Stylophora*). — KROPP & BIRKELAND, 1981: 629, tab. 5 (Moorea, Takapoto; in coral *Pocillopora*). — ODINETZ, 1983: 205 (Moorea, Tahiti, Takapoto; in coral *Pocillopora*). — CHACE, 1988: 77 (Syn.).

Synalpheus heroni Coutière, 1909

DISTRIBUTION. — Society (Bora Bora, Moorea, Tahiti) - *Free living or coral associate (Gen.* Acropora*).*

REFERENCES. — ***Synalpheus heroni*** - BANNER & BANNER, 1967: 264 ("BD2, various coral heads" = Tahiti, "BD17, from partially living *Acropora* and coralline alga" = Bora Bora, "BD32, from ridge of calcareous alga" = Moorea).

Synalpheus nilandensis Coutière, 1905a

DISTRIBUTION. — Gambier (Mangareva) - *Bivalve associate (Gen.* Pinctada*).*

REFERENCES. — ***Synalpheus nilandensis*** - NOBILI, 1907: 353 (Mangareva). — SEURAT, 1934: 60 (Mangareva; in pearl oyster *Pinctada margaritifera*). — BANNER & BANNER, 1983: 101 (Syn.). — CHACE, 1988: 82 (Syn.)

Synalpheus paraneomeris Coutière, 1905a

DISTRIBUTION. — Society (Bora Bora, Moorea, Tahiti); Tuamotu (Marutea South, Takapoto) - *Free-living or coral associate (Gen.* Acropora, Pocillopora*).*

REFERENCES. — ***Synalpheus paraneomeris*** - COUTIÈRE, 1905b: 22 (Marutea). — SEURAT, 1934: 60 (Marutea South). — BANNER & BANNER, 1967: 262 ("BD2, various coral heads, BD6, barrier reef, BD30, various coral heads" = Tahiti, "BD17, from partially living *Acropora* and coralline alga" = Bora Bora, "BD32, from ridge of calcareous alga, BD33" = Moorea). — MIYA, 1972: 54, pl. 9 (Syn.). — ODINETZ, 1983: 208 (Tahiti; in coral *Pocillopora*, non obligate associate; Takapoto also indicated in Paris collections). — CHACE, 1988: 83 (Syn.).

Synalpheus streptodactylus streptodactylus Coutière, 1905a

DISTRIBUTION. — Society (Moorea, Tahiti); Tuamotu (Takapoto) - *Free-living or coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Synalpheus streptodactylus streptodactylus*** - BANNER & BANNER, 1966a: 157 (Syn.); 1967: 264 ("BD34, behind the reef" = Moorea). — MIYA, 1972: 69, pl. 14 (Syn.) — ***Synalpheus streptodactylus*** - ODINETZ, 1983: 208 (Tahiti; in coral *Pocillopora*, non obligate associate; Takapoto also indicated in Paris collections).

FAMILY HIPPOLYTIDAE

Hippolyte ventricosa H. Milne Edwards, 1837

DISTRIBUTION. — Society (Moorea) - *In algae (Gen.* Turbinaria*).*

REFERENCES. — ***Hippolyte ventricosa*** - HOLTHUIS, 1947: 55, fig. 7-9 (Syn.). — NAIM, 1980, annexe 1-2 (Moorea; in algae *Turbinaria ornata*).

REMARK. — According to C. d'UDEKEM D'ACOZ (personal communication) most of the Indo-Pacific references to *H. ventricosa* need a revision.

Ligur ensiferus (Risso, 1816)

DISTRIBUTION. — Austral (Raevavae, Rapa, Rurutu); Gambier; Tuamotu (Maria) - *Deep (290-380m).*

REFERENCES. — ***Ligur ensiferus*** - POUPIN *et al.*, 1990: 15 (French Polynesia). — POUPIN, 1996b: 6, pl. 2d (Gambier, Maria, Raevavae, Rapa, Rurutu; 290-380m).

Lysmata amboinensis (de Man, 1888)

DISTRIBUTION. — Marquesas (Ua Pou) - *Littoral to deep (120m).*

REFERENCES. — ***Lysmata amboinensis*** - POUPIN, 1996b: 6, pl. 2e (Ua Pou; 120m).

Merhippolyte kauiaensis Rathbun, 1906

DISTRIBUTION. — Marquesas (Tahuata) - *Deep (530m).*

REFERENCES. — ***Merhippolyte kauiaensis*** - POUPIN *et al.*, 1990: 15 ("French Polynesia"; exact location, not indicated in text, is Tahuata, 530m; MNHN Na13299).

Parhippolyte uveae Borradaile, 1900

DISTRIBUTION. — Society (Maupiti, Raiatea) - *Deep (110-130m).*

REFERENCES. — ***Parhippolyte uveae*** - POUPIN, 1996b: 6, pl. 2f (Maupiti, Raiatea; 110-130m; usually this species is littoral).

Saron marmoratus (Olivier, 1811)

DISTRIBUTION. — Gambier (Mangareva); Marquesas (Nuku Hiva); Society (Tahiti); Tuamotu (Amanu, ?Moruroa) - *Coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Hippolyte gibbosus*** - HELLER, 1865: 120 (Tahiti). — ***Hippolyte gibberosa*** - ORTMANN, 1890: 497 (HELLER's reference). — ***Saron gibberosus*** - NOBILI, 1907: 358 ("Rikitea" = Mangareva, "Omanu" = Amanu). — SENDLER, 1923: 46 (Tahiti). — ***Saron marmoratus*** - BOONE, 1935: 187, pl. 51 (Nuku Hiva). — HOLTHUIS, 1947: 6 (Syn.) - RELEVANT MATERIAL - ***Saron* sp. aff. *marmoratus*** - Coll. J. POUPIN, det. A.J. BRUCE (Moruroa; in coral *Pocillopora*) - SYNONYM - *Hippolyte gibberosus* H. Milne Edwards, 1837.

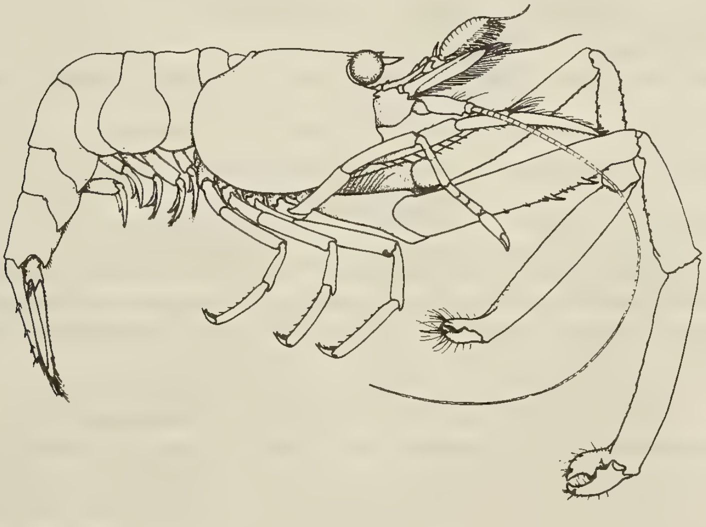

Figure 4 - *Thorina maldivensis* (Borradaile, 1915)
(From BRUCE, 1997)

Saron neglectus De Man 1902

DISTRIBUTION. — Society (Moorea, Tahiti); Tuamotu (Takapoto) - *In algae (Gen.* Giffordia, Halimeda, Liagora, Turbinaria*) or in coral (Gen.* Pocillopora*).*

REFERENCES. — ***Saron neglectus*** - NAIM, 1980, annex 1-2 (Moorea; *in algae Giffordia mitchellae, Halimeda opuntia, Liagora hawaiiana, Turbinaria oranata*). — KROPP & BIRKELAND, 1981: 630, tab. 5 (Moorea; in coral *Pocillopora*, non obligate associate). — ODINETZ, 1983: 207 (Moorea, Tahiti, Takapoto; in coral *Pocillopora*, non obligate associate) — ODINETZ-COLLART & RICHER DE FORGES, 1985: 201 (Moorea, Tahiti, Takapoto; in coral *Pocillopora*).

Thor amboinensis **(De Man, 1888)**

DISTRIBUTION. — Tuamotu (Fangataufa) - *Coral associate (Gen.* Acropora*).*

REFERENCES. — ***Thor amboinensis*** - NEW MATERIAL - Coll. J. POUPIN, February 1996, det. A.J. BRUCE (Fangataufa; in coral *Acropora*, 10m; MNHN Na13303).

Thor paschalis **Heller, 1862**

DISTRIBUTION. — Society (Moorea) - *In algae (Gen.* Codium*).*

REFERENCES. — ***Thor paschalis*** - HOLTHUIS, 1947: 49 (Syn.). — NAIM, 1980, annex 1-2 (Moorea; in algae *Codium geppii*).

Thorina maldivensis **(Borradaile, 1915)**

DISTRIBUTION. — Society (Moorea, Tahiti); Tuamotu (Takapoto) - *Free-living or coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Thor maldivensis*** - ODINETZ, 1983: 207 (Moorea, Tahiti, Takapoto; in coral *Pocillopora*, non obligate associate). — ***Thorina maldivensis*** - BRUCE, 1997: 14, fig. 1-6 (Tahiti).

FAMILY PROCESSIDAE

Nikoides **aff.** ***danae*** **Paulson, 1875**

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Nikoides*** **aff.** ***danae*** - NEW MATERIAL - Coll. P. FROUIN, preliminary det. P. NOEL, MNHN Na13053-54 (Tahiti).

Processa **aff.** ***moana*** **Yaldwyn, 1971**

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Processa*** **aff.** ***moana*** - NEW MATERIAL - Coll. P. FROUIN, preliminary det. P. NOEL, MNHN Na13055 (Tahiti).

FAMILY PANDALIDAE

Chlorocurtis jactans **(Nobili, 1904)**

DISTRIBUTION. — Society (Moorea, Tahiti) - *Free-living, algae (Gen.* Turbinaria*) or coral associate (Gen.* Pocillopora*).*

REFERENCES. — ***Chlorocurtis jactans*** - NAIM, 1980, annex 1-2 (Moorea; in algae *Turbinaria ornata*). — ODINETZ, 1983: 207 (Moorea, Tahiti; in coral *Pocillopora*, non obligate associate).

Heterocarpus **aff.** ***ensifer*** **A. Milne Edwards, 1881**

DISTRIBUTION. — Marquesas (Eiao, Fatu Hiva, Hiva Oa, Tahuata, Ua Pou) - *Deep (217-730m, mostly 300-400m).*

REFERENCES. — ***Heterocarpus*** **aff.** ***ensifer*** - POUPIN *et al.*, 1990: 16, 50, fig. 5-7, 11, pl. 1d (French Polynesia). — POUPIN, 1996b: 6, pl. 2g (Eiao, Fatu Hiva, Hiva Oa, Tahuata, Ua Pou; 217-730m). — ***Heterocarpus ensifer*** - POUPIN & RICHER DE FORGES, 1991: 211, fig. 1 (French Polynesia). — Not *Heterocarpus ensifer* - MANAC'H & CARSIN, 1985: 473. — CROSNIER, 1986a: 362. — POUPIN, 1988: 27, fig. 2, 5 - These three references concerned *H. amacula* Crosnier and/or *H. parvispina* de Man.

Heterocarpus amacula **Crosnier, 1988b**

DISTRIBUTION. — Austral (Rapa, Tubuai); Gambier; Society (Tahiti); Tuamotu (Fangataufa, Moruroa) - *Deep (250-800m, mostly 450-650m).*

REFERENCES. — ***Heterocarpus ensifer*** - MANAC'H & CARSIN, 1985: 473 (Moruroa and/or Fangataufa). — CROSNIER, 1986a: 362 (Moruroa, Tahiti, Tubuai). — POUPIN, 1988: 27, fig. 2, 5 (Moruroa) - All not *H. ensifer* A. Milne Edwards = *H. amacula* sp. nov. *in* CROSNIER (1988b); some sp. are *H. parvispina* de Man). — ***Heterocarpus amacula*** Crosnier, 1988b: 72, fig. 4a, pl. 1b, 2h (Tubuai, Moruroa). — POUPIN *et al.*, 1990: 15, 56, fig. 5, 6, 7, 12, pl. 1c (French Polynesia). — POUPIN & RICHER DE FORGES, 1991: 211, fig. 1 (French Polynesia). — POUPIN, 1996b: 6, pl. 2h (Fangataufa, Gambier, Moruroa, Rapa, Tahiti, Tubuai; 250-800m).

Heterocarpus dorsalis **Bate, 1888**

DISTRIBUTION. — Marquesas (Tahuata); Society (Tahiti); Tuamotu (Makemo) - *Deep (680-1025m).*

REFERENCES. — ***Heterocarpus dorsalis*** - CROSNIER, 1986a: 362; 1988b: 62, fig. 2-3 (Tahiti). — POUPIN *et al.*, 1990: 16 (French Polynesia). — POUPIN, 1996b: 8, pl. 3a (Makemo, Tahiti, Tahuata; 680-1025m).

Heterocarpus laevigatus Bate, 1888

DISTRIBUTION. — Austral (Rapa, Tubuai); Gambier; Marquesas; Society (Bellingshausen, Huahine, Tahiti); Tuamotu (Fangataufa, Moruroa) - *Deep (410-1050m; mostly 500-800m).*

REFERENCES. — ***Heterocarpus laevigatus*** - CROSNIER, 1986a: 362 (Tahiti, Tubuai); 1988b: 74 (Tubuai). — POUPIN *et al.*, 1990: 16, 37, fig. 5, 6, 7, 9, pl. 1e (French Polynesia). — POUPIN, 1996b: 8, pl. 3b (Bellingshausen = Motu One, Fangataufa, Gambier, Huahine, Marquesas, Moruroa, Rapa, Tubuai; 410-1050m).

Heterocarpus longirostris McGilchrist, 1905

DISTRIBUTION. — Tuamotu (Hao, Moruroa) - *Deep (1010-1020m).*

REFERENCES. — ***Heterocarpus longirostris*** - POUPIN, 1996b: 8, pl. 3c (Hao, Moruroa; 1010-1020m).

Heterocarpus parvispina de Man, 1917

DISTRIBUTION. — Austral (Tubuai); Society; Tuamotu (Fangataufa, Moruroa) - *Deep (230-730m; mostly 350-500m).*

REFERENCES. — ***Heterocarpus parvispina*** - CROSNIER, 1988b: 70, 72, fig. 5a, pl. 1a, 2g (Moruroa, Tubuai). — POUPIN *et al.*, 1990: 16, 60, fig. 5-7, 13, pl. 1b (French Polynesia).— POUPIN & RICHER DE FORGES, 1991: 211, fig. 1 (French Polynesia). — POUPIN, 1996b: 8, pl. 3d (Fangataufa, Moruroa; Austral, Society; 230-730m). — ***Heterocarpus ensifer***. — MANAC'H & CARSIN, 1985: 473. — CROSNIER, 1986a: 362. — POUPIN, 1988: 27, fig. 2, 5, 6 - All, *pro parte* not *H. ensifer* A. Milne Edwards, 1881 but a mixture of *H. parvispina* and *H. amacula.*

Heterocarpus sibogae de Man, 1917

DISTRIBUTION. — Austral (Tubuai); Society (Tahiti); Tuamotu (Moruroa) - *Deep (190-950m).*

REFERENCES. — ***Heterocarpus sibogae*** - CROSNIER, 1986a: 362 (Tahiti); 1988b: 79, fig. 5c, pl. 1c, 3a-b (Tahiti, Tubuai; Tuamotu). — POUPIN, 1988: 27, fig. 2 (Moruroa); 1996b: 8, pl. 3e (Moruroa, Tahiti, Tubuai; 190-950m). — POUPIN *et al.*, 1990: 16, 45, fig. 5-7, 10, pl. 1f (French Polynesia). — POUPIN & RICHER DE FORGES, 1991: 211 (French Polynesia).

Plesionika carsini Crosnier, 1986a

DISTRIBUTION. — Austral (Maria, Raevavae, Tubuai); Gambier; Marquesas (Ua Pou); Tuamotu (Makemo, Maria, Moruroa, Tureia) - *Deep (410-600m).*

REFERENCES. — ***Plesionika carsini*** Crosnier, 1986a: 369, fig. 3a-i (Moruroa). — POUPIN *et al.*, 1990: 16, pl. 2b (French Polynesia). — POUPIN & RICHER DE FORGES, 1991: 211 (French Polynesia). — POUPIN, 1996b: 8, pl. 3f (Gambier, Makemo, Maria, Moruroa, Raevavae, Tubuai, Tureia, Ua Pou; 430-600m; in these locations some specimens must belong to *Plesionika picta* Chan & Crosnier). — CHAN & CROSNIER, 1997: 190, fig. 2a, 2b, fig. 21 (Fangataufa, Gambier, Makemo, Maria, Moruroa, Tureia; 410-510m).

Plesionika curvata Chan & Crosnier, 1991

DISTRIBUTION. — Austral (Rapa, Rimatara, Tubuai); Gambier; Tuamotu (Fangataufa) - *Deep (150-400m).*

REFERENCES. — ***Plesionika* sp. nov. 2** - POUPIN *et al.*, 1990: 16, pl. 3f (French Polynesia). — ***Plesionika curvata*** Chan & Crosnier, 1991: 440, fig. 10b, 11d-f, 33 (Fangataufa, Gambier, Rapa, Tubuai). — POUPIN, 1996b: 8, pl. 3g (Fangataufa, Gambier, Rapa, Rimatara, Tubuai; 150-400m).

Plesionika edwardsii (Brandt, 1851)

DISTRIBUTION. — Austral (Raevavae, Rapa, Tubuai); Gambier; Marquesas; Society (Tahiti); Tuamotu (Fangataufa, Moruroa) - *Deep (200-500m; mostly 250-350m).*

REFERENCES. — ***Plesionika edwardsii*** - MANAC'H & CARSIN, 1985: 473 (Fangataufa and/or Moruroa). — CROSNIER, 1986a: 362 (Moruroa, Tahiti, Tubuai). — POUPIN, 1988: 28, fig. 2 (Moruroa); 1996b: 8, pl. 3h (Fangataufa, Gambier, Marquesas, Moruroa, Tahiti, Tubuai; 220-500m). — POUPIN *et al.*, 1990: 16, 68, fig. 5, 6, 7, 15, pl. 1g (French Polynesia). — CHAN & CROSNIER, 1997: 193, fig. 23 (Moruroa, Raevavae, Rapa, Tahiti, Tubuai; 200-450m).

Plesionika erythrocyclus Chan & Crosnier 1997

DISTRIBUTION. — Austral (Rurutu); Tuamotu (Moruroa) - *Deep (200-260m).*

REFERENCES. — ***Plesionika* sp. nov. 1** - POUPIN, 1996b: 10, pl. 4a (Moruroa, Rurutu; 200-260m). — ***Plesionika erythrocyclus*** Chan & Crosnier, 1997: 214, fig. 16, 34-35 (Moruroa, Rurutu; 200-260m; Syn.)

Plesionika fenneri Crosnier, 1986b

DISTRIBUTION. — Austral (Rapa, Rurutu, Tubuai); Gambier; Marquesas; Society; Tuamotu (Fangataufa, Maria, Moruroa) - *Deep (260-820m; mostly 500-700m).*

REFERENCES. — ***Plesionika chacei*** Crosnier, 1986a: 363, fig. 1a-b, 2a-h (Moruroa, Tubuai). — ***Plesionika fenneri*** Crosnier, 1986b: 691 (new name for *P. chacei*). — POUPIN, 1988: 28, fig. 2, 4-6 (Moruroa); 1996b: 10, pl. 4b (Fangataufa, Moruroa, Rapa, Tubuai; Marquesas & Society; 260-820m). — POUPIN *et al.*, 1990: 16, 29, fig. 5-8, pl. 1a (French Polynesia). — POUPIN & RICHER DE FORGES, 1991: 211 (French Polynesia). — CHAN &CROSNIER, 1997: 196, fig. 4, 26-27 (Gambier, Maria, Rurutu; 470-660m). — ***Plesionika* aff. *trispinus*** (sic) - POUPIN *et al.*, 1990: 16 ("French Polynesia"; exact location, not indicated, is Maria, 680m) - Not *P. trispinosus* Squires & Barraguan, 1976 = *P. fenneri* juvenile *fide* CHAN & CROSNIER (1997: 196).

Plesionika flavicauda Chan & Crosnier, 1991

DISTRIBUTION. — Austral (Rurutu, Tubuai); Society (Tahiti); Tuamotu (Fangataufa, Moruroa, Takapoto) - *Deep (100-260m).*

REFERENCES. — ***Plesionika* sp. nov. 1** - POUPIN *et al.*, 1990: 16, pl. 3e (French Polynesia). — ***Plesionika flavicauda*** Chan & Crosnier, 1991: 438, fig. 10a, 11a-c, 29-32 (Fangataufa, Moruroa, Rurutu, Tahiti, Takapoto). — POUPIN, 1996b: 10, pl. 4c (same islands; 100-260m). — ? ***Plesionika serratifrons*** - CROSNIER, 1986a: 362 (Tahiti, Tubuai) not *P. serratifrons* (Borradaile, 1900); material not retrieved in MNHN but most probably belonging to *P. flavicauda.*

Plesionika macropoda Chace, 1939

DISTRIBUTION. — Austral (Maria); Gambier; Marquesas (Ua Pou); Society (Huahine); Tuamotu (Maria, Moruroa, Tureia) - *Deep (300-600m).*

REFERENCES. — ***Plesionika* aff. *williamsi*** - POUPIN *et al.*, 1990: 16 (French Polynesia), in part not *P. williamsi* Forest, 1964. — ***Plesionika macropoda*** - POUPIN, 1996b: 10, pl. 4d (Gambier, Huahine, Maria, Moruroa, Tureia, Ua Pou; 300-600m). — CHAN & CROSNIER, 1997: 205, fig. 11-13, 30-31 (Gambier, Huahine, Maria [Austral & Tuamotu], Moruroa, Ua Pou; 310-500m; Syn.).

Plesionika martia (A. Milne Edwards, 1883)

DISTRIBUTION. — Marquesas (Nuku Hiva, Ua Pou) - Deep *(590-650m).*

REFERENCES. — ***Plesionika martia*** - CHAN & CROSNIER, 1997: 213 (Ua Pou, Nuku Hiva; 590-650m).

Plesionika narval (Fabricius, 1787)

DISTRIBUTION. — Society (Tahiti) - *Sublittoral (40-50m).*

REFERENCES. — ***Plesionika narval*** - CHAN & CROSNIER, 1991: 443, fig. 12a-c, 13a, 14a-c, 15a-e, 34-36 (Tahiti; 40-50m).

Plesionika nesisi (Burukovsky, 1986)

DISTRIBUTION. — Marquesas (Hiva Oa); Society (Huahine); Tuamotu (Fangataufa, Makemo, Moruroa) - *Deep (550-1080m; mostly 800-1000m).*

REFERENCES. — ***Plesionika* aff. *laevis*** - POUPIN *et al.*, 1990: 16, 72, fig. 16, pl. 2a (French Polynesia). — ***Plesionika nesisi*** - POUPIN, 1996b: 10, pl. 4e (Fangataufa, Hiva Oa, Huahine, Makemo, Moruroa; 550-1080m). — CHAN & CROSNIER, 1997: 197, fig. 5-10, 28 (Fangataufa, Hiva Oa, Makemo, Moruroa; 600-1050m).

Plesionika payeni Chan & Crosnier, 1997

DISTRIBUTION. — Tuamotu (Moruroa) - *Deep (200-250m).*

REFERENCES. — ***Plesionika* sp. nov. 5** - POUPIN, 1996b: 12, pl. 5g (Moruroa; 250m). — ***Plesionika payeni*** Chan & Crosnier, 1997: 221: fig. 19, 39 (Moruroa, 200-250m).

Plesionika picta Chan & Crosnier, 1997

DISTRIBUTION. — Austral (Maria, Rurutu); Tuamotu (Fangataufa, Moruroa) - *Deep (520-710m).*

REFERENCES. — ***Plesionika* sp. nov. 2** - POUPIN, 1996b: 10, pl. 4f (Fangataufa, Maria, Moruroa, Rurutu; 650-710m). — ***Plesionika picta*** Chan & Crosnier, 1997: 223, fig. 20, 40 (Fangataufa, Gambier, Maria, Rurutu, Ua Pou; 520-710m).

Plesionika poupini Chan & Crosnier, 1997

DISTRIBUTION. — Austral (Raevavae, Rimatara, Rurutu); Gambier; Tuamotu (Fangataufa, Makemo, Maria, Moruroa, Tureia) - *Deep (260-650m).*

REFERENCES. — ***Plesionika carsini*** - CROSNIER, 1986a: 369. — POUPIN & RICHER DE FORGES, 1991: 211 - Both references, *pro parte*, not *P. carsini* Crosnier 1986 = *P. poupini* Chan & Crosnier, 1997. — ***Plesionika* aff. *carsini*** - POUPIN *et al.*, 1990: 16, pl. 3h (French Polynesia). — ***Plesionika* sp. nov. 3** - POUPIN, 1996b: 10, pl. 4g (Fangataufa, Gambier, Makemo, Maria, Moruroa, Raevavae, Rimatara, Rurutu, Tureia; 280-650m). — ***Plesionika poupini*** Chan & Crosnier, 1997: 189, fig. 1-2, 22 (Fangataufa, Makemo, Maria, Moruroa, Raevavae, Rimatara, Rurutu; 260-600m).

Plesionika protati Chan & Crosnier, 1997

DISTRIBUTION. — Marquesas (Fatu Hiva, Nuku Hiva, Tahuata) - *Deep (190-230m).*

REFERENCES. — ***Plesionika* sp. nov. 4** - POUPIN, 1996b: 4, pl. 4h (Fatu Hiva, Tahuata; 190-210m). — ***Plesionika protati*** Chan & Crosnier, 1997: 219, fig. 18, 38 (Fatu Hiva, Nuku Hiva, Tahuata; 190-230m).

Plesionika reflexa Chace, 1985

DISTRIBUTION. — Austral (Rimatara, Tubuai); Gambier; Marquesas (Fatu Hiva); Society; Tuamotu (Moruroa, Tureia) - *Deep (360-910m; mostly 550-700m).*

REFERENCES. — ***Plesionika reflexa*** - CROSNIER, 1986a: 362 (Tubuai). — POUPIN, 1996b: 12, pl. 5a (Gambier, Fatu Hiva, Moruroa, Rimatara, Tubuai, Tureia; Society; 360-910m). — CHAN & CROSNIER, 1997: 194, fig. 3, 24 (Fatu Hiva, Maria, Moruroa, Rimatara, Tubuai, Tureia; 430-800m). — ***Plesionika ensis*** - POUPIN *et al.*, 1990: 16, 64, fig. 5-7, 14, pl. 1h (French Polynesia). — ***Plesionika* aff. *ensis*.** — POUPIN, 1988: 28, fig. 2 (Moruroa) - Both, not *P. ensis* A. Milne Edwards, 1881 = *P. reflexa* Chace, 1985.

Plesionika rubrior Chan & Crosnier, 1991

DISTRIBUTION. — Austral (Rimatara, Rurutu); Society (Maiao, Tahiti); Tuamotu (Moruroa, Nihuru, Takapoto, Tenarunga) - *Deep (120-350m).*

REFERENCES. — ? ***Plesionika pacifica*** - MANACH & CARSIN, 1985: 473 (Moruroa and/or Fangataufa). — CROSNIER, 1986a: 362 - Both, ? not *P. pacifica* Edmonson, 1952 = *P. rubrior* (*cf.* remark). — ***Plesionika* sp. nov. 3** - POUPIN *et al.*, 1990: 16 (French Polynesia). — ***Plesionika rubrior*** Chan & Crosnier, 1991: 433, fig. 7a-f, 25-28 (Syn.; Maiao, Moruroa, Nihuru, Rimatara, Rurutu, Tahiti, Takapoto, Tenarunga; 120-350m). — POUPIN, 1996b: 12, pl. 5b (Same material).

REMARK. — *Plesionika pacifica* is mentioned from a lost specimen, caught around Moruroa. Although not verifiable, the exact identity of this material would rather be *P. rubrior*.

Plesionika semilaevis Bate, 1888

DISTRIBUTION. — Austral (Tubuai) - *Deep (800m).*

REFERENCES. — ***Plesionika semilaevis*** - CHAN & CROSNIER, 1997: 213 (Tubuai; 800m).

Plesionika sindoi (Rathbun, 1906)

DISTRIBUTION. — Austral (Maria, Raevavae, Rurutu); Gambier; Marquesas (Fatu Hiva, Tahuata); Society (Bora Bora); Tuamotu (Fangataufa, Makemo, Moruroa, Tuanake) - *Deep (150-800m, mostly 300-600m).*

REFERENCES. — ***Plesionika* aff. *ocellus*** - ? POUPIN *et al.*, 1990: 16 (French Polynesia). — ***Plesionika sindoi*** - POUPIN, 1996b: 12, pl. 5c (Bora Bora, Fangataufa, Fatu Hiva, Gambier, Makemo, Maria [Austral & Tuamotu], Moruroa, Raevavae, Rurutu, Tahuata; 150-800m). — CHAN & CROSNIER, 1997: 216, fig. 17, 36-37 (Bora Bora, Fangataufa, Fatu Hiva, Gambier, Makemo, Maria [Austral & Tuamotu], Moruroa, Raevavae, Rurutu, Tunake; 380-780m).

Plesionika spinidorsalis (Rathbun, 1906)

DISTRIBUTION. — Austral (Tubuai); Gambier; Society (Bora Bora, Huahine); Tuamotu (Moruroa) - *Deep (300-750m).*

REFERENCES. — ***Plesionika spinidorsalis*** - POUPIN *et al.*, 1990: 16 (French Polynesia). — POUPIN, 1996b: 12, pl. 5e (Bora Bora, Gambier, Huahine, Moruroa, Tubuai; 300-750m). — CHAN & CROSNIER, 1997: (Bora Bora, Gambier, Huahine, Moruroa, Tubuai; 540-720m).

Plesionika spinipes Bate, 1888

DISTRIBUTION. — Society (Maiao, Tahiti) - *Deep (320-600m).*

REFERENCES. — ***Plesionika spinipes*** - CROSNIER, 1986a: 362 (Tahiti). — CHAN & CROSNIER, 1991: 422, fig. 1b-c, 3e, 21 (Maiao, "Taravao" = Tahiti; 320-600m). — POUPIN, 1996b: 12, pl. 5d (Same material).

Plesionika williamsi Forest, 1964

DISTRIBUTION. — Austral (Rurutu); Gambier; Marquesas (Eiao, Tahuata, Ua Pou); Society (Huahine, Bellingshausen, Tahiti); Tuamotu (Fangataufa, Makemo, Marutea South, Moruroa) - *Deep (310-600m).*

REFERENCES. — ***Plesionika* aff. *williamsi*** - CROSNIER, 1986a: 373, fig. 4a-g (Tahiti). — POUPIN *et al.*, 1990: 16 (French Polynesia), in part, see under *P. macropoda*. — ***Plesionika williamsi*** - POUPIN, 1996b: 12, pl. 5f (Bellinghausen, Eiao, Fangataufa, Gambier, Makemo, Marutea South, Moruroa, Rurutu, Tahiti, Tahuata, Ua Pou; 310-470m). — CHAN & CROSNIER, 1997: 209, fig. 14-15, 32-33 (Syn.; Bellingshausen, Eiao, Fangataufa, Makemo, Marutea South, Moruroa, Tahiti, Tahuata, Tubuai, Ua Pou; 350-600).

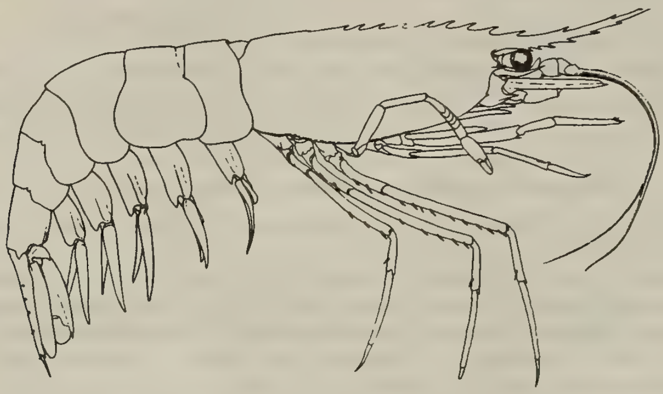

Figure 5 - *Plesionika spinidorsalis* (Rathbun, 1906)
(From CHACE, 1985)

FAMILY CRANGONIDAE

Presence of the deep crangonids in French Polynesia is attested by a single small specimen in bad condition (telson is missing) in the MNHN collections (Coll. RV *Marara*, B. RICHER DE FORGES, May 1979, Tubuai, 300m; material not recorded). It is attributed to *Philocheras* sp. (det. A. CROSNIER). This first report is confirmed by collection of several other deep crangonids around the Marquesas during the recent RV *Alis* Marquesas Expedition, August/September 1997 (J. POUPIN field notes).

FAMILY THALASSOCARIDIDAE

Thalassocaris aff. *crinita* (Dana, 1852)

DISTRIBUTION. — Society? - *Bathypelagic (100m).*
REFERENCES. — ***Thalassocaris* aff. *crinita*** - NEW MATERIAL - Coll. E. JOSSE, det. J. POUPIN (French Polynesia, ?Society; 100m; material returned to ORSTOM/Tahiti).

INFRA-ORDER THALASSINIDEA

Thalassinidea are often hidden in deep burrows and are very difficult to collect. As a result, our knowledge of this group is superficial and the species listed below certainly represent only a small part of the real French Polynesian fauna. An example of an unknown species is given by a beautiful axiid photographed in Tahitian waters and illustrated in a local newspaper ("Le homard aux pinces d'or", *La Dépêche*, Tahiti, August 31th, 1994, p. 19, photograph D. PARDON).

First reports of Thalassinidea from French Polynesia were made by SENDLER (1923) and EDMONSON (1944). Subsequent collections made by, H.G. MÜLLER, researchers sojourning at the CRIOBE center (B. THOMASSIN, J. de VAUGELAS), or present author, are reported by THOMASSIN *et al.* (1982), DE VAUGELAS (1983, 1985), POORE & SUCHANEK (1988), SAKAI (1992), POUPIN (1994), NGOC-HO (1995, 1998), and POORE (1997). In Austral, Gambier, or Marquesas Islands, we still have no record of Thalassinidea.

FAMILY AXIIDAE

Eutrichocheles tuamotu Ngoc-Ho, 1998

DISTRIBUTION. — Tuamotu (Moruroa) - *Deep (140m).*

REFERENCES. — ***Eutrichocheles* tuamotu** Ngoc-Ho, 1998: in press (Moruroa; 140m).

REMARK. — According to NGOC-HO (personnal communication) this species would better be placed in the genus *Paraxiopsis* (see KENSLEY, 1996). This point will be discussed in her future publications.

Parascytoleptus tridens (Rathbun, 1906)

DISTRIBUTION. — Society (Bora Bora, Moorea); Tuamotu (Makatea).

REFERENCES. — ***Paraxius tridens*** - SENDLER, 1923: 44 (Makatea). — ***Parascytoleptus tridens*** - SAKAI & DE SAINT LAURENT, 1989: 40 (New combination). — SAKAI, 1992: 212 ("Vaitapu" = Bora Bora, "Maharepa & Afareaitu" = Moorea; coral and dead coral, 0.5-2m).

Paraxiopsis brocki (De Man, 1888)

DISTRIBUTION. — Society (Bora Bora); Tuamotu (Fangataufa).

REFERENCES. — ***Eutrichocheles brocki*** - SAKAI, 1992: 216 ("Vaitape" = Bora Bora; in coral 0.5-1m). — NGOC-HO, 1998: in press (Fangataufa; outer reef). — ***Paraxiopsis brocki*** - KENSLEY, 1996 (New combination).

FAMILY CALLIANASSIDAE

Cheramus articulatus (Rathbun, 1906) - New combination

DISTRIBUTION. — Tuamotu (Mataiva) - *Burrower.*

REFERENCES. — ***Callichirus articulatus*** - VAUGELAS, 1985: 316 (Mataiva).

REMARK. — MANNING & FELDER (1986) do not include RATHBUN's species in their definition of the genus *Callichirus.* In MNHN collections, material from the Tuamotu is represented by one male (c.l. 11.5 mm, MNHN Th1232). Its examination shows that: a) Maxillipedal 3 dactylus is digitiform; b) Pleopods 3-5 have digitiform appendices internae; c) Maxilliped 3 is without exopod. In POORE (1994: 101), this key out to the genus *Cheramus.* We therefore propose here a new combination for this species.

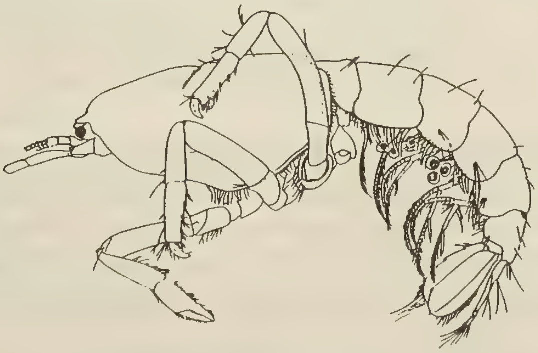

Figure 6 - *Parascytoleptus tridens* (Rathbun, 1906)
(From SAKAI & DE SAINT LAURENT, 1989)

Corallianassa collaroy (Poore & Griffin, 1979)

DISTRIBUTION. — Society (Moorea, Tahiti).

REFERENCES. — ***Corallianassa collaroy*** - SAKAI, 1992: 212, fig. 1a-d (Moorea, Tahiti).

Glypturus armatus (A. Milne Edwards, 1870)

DISTRIBUTION. — Society (Moorea, Tahiti); Tuamotu (Mataiva, Takapoto, Tikehau) - *Burrower*.

REFERENCES. — ***Callichirus armatus*** - VAUGELAS, 1983: 23 (Mataiva, Moorea, Tahiti); 1985: 314 (Mataiva). — DELESALLE, 1985: 288, 295, 299 (Mataiva). — HARMELIN-VIVIEN, 1985: 251 (Tikehau). — SALVAT & RICHARD, 1985: 353 (Takapoto). — VAUGELAS *et al.*, 1986: 204, fig. 1-3 (Mataiva, Moorea, Tahiti). — ***Callianassa armata*** - MANNING, 1987: 390 (Synonymize this species with *Glypturus acanthochirus*). — ***Glypturus armatus*** - POORE & SUCHANEK, 1988: 197, 201 (Mataiva, VAUGELAS' material, with this remark "We do not agree with MANNING (1987) who believed that *G. armatus* is a junior synonym of *G. acanthochirus*").

Neocallichirus taiaro Ngoc-Ho, 1995

DISTRIBUTION. — Tuamotu (Taiaro) - *Burrower*.

REFERENCES. — ***Neocallichirus taiaro*** Ngoc-Ho, 1995: 211, fig. 1-2 (Taiaro).

FAMILY CALLIANIDEIDAE

Callianidea typa H. Milne Edwards, 1837

DISTRIBUTION. — Tuamotu (Moruroa, Taiaro) - *Burrower*.

REFERENCES. — ***Callianidea typa*** - EDMONSON, 1944: 38, fig. 2 (Tahiti). — POUPIN, 1994: 7, fig. 3, pl. 1b (Taiaro). — POORE, 1997: 349, fig. 1-3, 4a-b (Taiaro) - NEW MATERIAL - Coll. & det. J. POUPIN, October 1995 (Moruroa; sandy area, under rocks).

FAMILY THOMASSINIIDAE

Thomassinia moorea Poore, 1997

DISTRIBUTION. — Society (Moorea).

REFERENCES. — ***Thomassinia*** sp. - THOMASSIN *et al.*, 1982: 394 (Moorea). — ***Thomassinia moorea*** Poore, 1997: 416, fig. 38 (Moorea).

REMARK. — Two others Thomassiniidae, attributed by POORE (1997: 408) to "? *Mictaxius* sp.", were also collected with this new species. The specimens are in poor condition and POORE writes "While the species is represented by such incomplete specimens, its generic placement is uncertain".

ORDER STOMATOPODA

Collections of Stomatopoda roughly follow those recorded in the Caridea section with the addition of the following Expeditions: the U.S.S. *Wachusett* Expedition, Marquesas 1884, coll. Dr. William H. JONES, U.S. Navy (BIGELOW, 1931), the 1899-1900 *Albatross* Voyage (MANNING, 1978c), the 1901-1902 American *Alvin Seale* cruise (EDMONSON, 1921), and the 1957 SMITHSONIAN BREDIN Expedition (MANNING, 1978c). Material from these cruises is deposited at USNM, Washington, or BPBM, Honolulu.

Surprisingly, two species are deposited at the Indian Museum, Calcutta, *Pseudosquillisma oculata* (Brullé, 1837) and *Gonodactylus platysoma* Wood Mason, 1895 (type species) (KEMP, 1913; GOSH & MANNING, 1988). This material was donated to the Indian Museum by the OTAGO Museum, before 1895

(MANNING personal communication). OTAGO Museum is the Museum of Otago province, New Zealand, and was founded in 1868 (HOLTHUIS, personal communication).

Individual collectors of Stomatopoda include, J.M. CLEMENTS (1927, Society), priest Siméon DELMAS (1927, Marquesas), G. PINCHOT (1929, Tuamotu), G. RANSON (1952, Society), J. RANDALL (1957, Marquesas), R. WATKINS (1962, Society), and A. MICHEL (1969, Marquesas). People sojourning at Moorea research centers, CRIOBE and/or BERKELEY station, have also collected stomatopods: O. NAIM, M. MONTEFORTE, B. THOMASSIN, M. PEYROT-CLAUSADE and R. CALDWELL (*cf.* MANNING, 1978a). This material is deposited at the BPBM, Honolulu, USNM, Washington, or SME, Endoume.

Deep collections by the RV *Marara* include the big *Indosquilla manihinei* Ingle & Merrett, 1971 (illustrated in POUPIN, 1996b: 42, pl. 20 f-g) and two littoral to sublittoral species, here reported for the first time: *Odontodactylus brevirostris* (Miers, 1884) and *Oratosquilla calumnia* (Townsley, 1953). From ORSTOM Tahiti research center (coll. P. FROUIN) and unpublished material in MNHN and USNM (det. R.B. MANNING), three other species are also added to the regional fauna: *Alima alba* (Bigelow, 1893), *Busquilla quadraticauda* (Fukuda, 1911), and *Gonodactylus childi* Manning, 1971.

Material collected by H.G. MÜLLER in 1988 at Bora Bora and Moorea, Society Islands, is properly registered in MNHN (Sto 1658-1674) but was not retrieved. It could be from these field collections that *Gonodactylus platysoma* Wood-Mason, 1895 and *Raoulserenea ornata* (Miers, 1880) are listed from Moorea, to our knowledge for the first time, in MÜLLER (1994)'s world bibliography of Stomatopoda.

FAMILY INDOSQUILLIDAE

Indosquilla manihinei Ingle & Merrett, 1971

DISTRIBUTION. — Tuamotu (Fangataufa) - *Deep (550m).*

REFERENCES. — ***Indosquilla manihinei*** - MANNING *et al.*, 1990: 314 (Biogeography). — MÜLLER, 1994: 8 (Syn.). — MANNING, 1995: 18, 28 (List; new family). — POUPIN, 1996: 42, pl. 20 f-g (Fangataufa; 550m).

FAMILY GONODACTYLIDAE

Gonodactylaceus falcatus (Forskål, 1775)

DISTRIBUTION. — Society (Moorea).

REFERENCES. — ***Gonodactylus falcatus*** - NAIM, 1980: 51, with a ? — ***Gonodactylaceus falcatus*** - MANNING, 1995: 19, 42-43 (List & key; new combination).

Gonodactylaceus randalli (Manning, 1978)

DISTRIBUTION. — Society (Moorea).

REFERENCES. — ***Gonodactylus randalli*** Manning, 1978b: 9, fig. 6, 12 (Holotype from Moorea). — MÜLLER, 1994: 41 (Syn.). — ***Gonodactylaceus randalli*** - MANNING, 1995: 19, 42, 43, 47 (List & key; new combination).

Gonodactylellus espinosus (Borradaile, 1898)

DISTRIBUTION. — Marquesas (Fatu Hiva); Society (Bora Bora, Moorea, Tahiti); Tuamotu (Fakarava, Mataiva).

REFERENCES. — ***Gonodactylus espinosus*** - MANNING, 1967a: 21, fig. 8 (Bora Bora, Fakarava). — MONTEFORTE, 1984: 173, annex 1, tab. a (Mataiva, Moorea, Tahiti); 1987: 8 (Moorea). — MÜLLER, 1994: 30 (Syn.). — ***Gonodactylellus espinosus*** - MANNING, 1995: 19, 56, 57 (List & key; new combination) - NEW MATERIAL - February 1996, Coll. J. POUPIN, det. R.B. MANNING (Fatu Hiva MNHN Sto 1960; in base of a coral *Pocillopora*).

Gonodactylellus incipiens (Lanchester, 1903)

DISTRIBUTION. — Society (Moorea, Tahiti); Tuamotu (Fakarava).

REFERENCES. — ***Gonodactylus incipiens*** - MANNING, 1967a: 18, fig. 7 (Fakarava). — MÜLLER, 1994: 34 (Syn.). — ***Gonodactylellus incipiens*** - MANNING, 1995: 19, 56, 57, 63, fig. 24, 25b (List & key; new combination) - NEW MATERIAL - MNHN Sto 1165-1166, det. R.B. MANNING (Moorea, Tahiti).

Gonodactylinus viridis (Serène, 1954)

DISTRIBUTION. — Society (Moorea, Tahiti); Tuamotu (Mataiva).

REFERENCES. — ***Gonodactylus viridis*** - MONTEFORTE, 1984: 173, annex 1, tab. a (Mataiva, Moorea, Tahiti); 1987: 8 (Moorea). — DELESALLE, 1985: 305 (Mataiva). — MÜLLER, 1994: 44 (Syn.). — ***Gonodactylinus viridis*** - MANNING, 1995: 19, 66, pl. 4, fig. 8c,d, 9c, 10e, 11c, 25a (List; new combination).

Gonodactylus childi Manning, 1971

DISTRIBUTION. — Society (Moorea).

REFERENCES. — ***Gonodactylus childi*** - NEW MATERIAL - MNHN Sto 1170, det. R.B. MANNING (Moorea).

REMARK. — According to MANNING (in preparation), the original account of *childi* included two species in two different genera. The holotype is a dwarf species, *Gonodactylus childi* sensu stricto, and the paratypes are a new *Gonodactylellus*. French polynesian specimens belong to *G. childi* sensu stricto.

Gonodactylus chiragra (Fabricius, 1781)

DISTRIBUTION. — Gambier (Mangareva); Marquesas (Nuku Hiva); Society (Moorea, Tahiti); Tuamotu (Hao, Kaukura, Fakahina, Makatea).

REFERENCES. — ***Gonodactylus chiragra*** - HELLER, 1865: 126 (Tahiti). — NOBILI, 1907: 410 ("Ohura-Hao" = Hao, Kaukura, Fakahina, "motu Marakuraku"=?). — SENDLER, 1923: 47 (Makatea). — EDMONSON, 1921: 300 (Marquesas). — BOONE, 1934: 11, pl. 2, fig. a, part (Nuku Hiva, Tahiti; not Bora Bora and Raiatea, see MANNING, 1967c: 103). — SEURAT, 1934: 61 ("Rikitea" = Mangareva, Hao, Fakahina, Kaukura). — MANNING, 1967c: 102 (Marquesas and Society islands; revision of BOONE's material but without precision of islands concerned and: "these specimens were not all examined"); 1995: 20, 69, 71, pl. 5-8, fig. 8e,f, 9a,b, 10a, 11a, 27a, 28-30 (List & key). — NAIM, 1980: 51 (Moorea; in algae *Halimeda opuntia*). — MÜLLER, 1994: 27 (Syn.) - NEW MATERIAL - Coll. C. HILY, det. K. MOOSA (Tahiti MNHN Sto 1959).

REMARK. — Except for BOONE's material, revised by MANNING (1967c), most of the old collections should be checked. "A suite of species, including virtually all members of *Gonodactylus*, has been confused with *G. chiragra* at one time or another" (MANNING, 1995: 74).

Gonodactylus platysoma Wood-Mason, 1895

DISTRIBUTION. — Marquesas; Society (Bora Bora, Moorea, Raiatea); Tuamotu (Raroia).

REFERENCES. — ***Gonodactylus platysoma*** Wood-Mason, 1895: 11, pl. 3, fig. 3-9 (Society Islands). — ***Gonodactylus chiragra*** var. ***acutus*** Lanchester - EDMONSON, 1921: 300 (Marquesas). — ***Gonodactylus chiragra*** var. ***tumidus*** - BOONE, 1934: 11, pl. 1, 2b, part (Bora Bora, Raiatea; see MANNING, 1967c). — ***Gonodactylus chiragra*** var. ***platysoma*** - KEMP, 1913: 162 (Society Islands; WOOD-MASON's material). — BIGELOW: 1931: 119 (Bora Bora). — HOLTHUIS, 1953a: 62 (Raroia). — MORRISON, 1954: 13 (Raroia). — ***Gonodactylus platysoma*** - MANNING, 1967c: 103 (Bora Bora, Raiatea; BOONE's material); 1995: 20, 69, 75, pl. 9, 10, fig. 9d, 10b, 11b, 27b, 31 (List & key; "type locality Society Islands, 17°00'S, 150°00'W"). — GHOSH & MANNING, 1988: 654 (Selection of a lectotype from Society Islands in the collections of Zoological Surey of India, Calcutta). — MÜLLER, 1994: 40 (Syn.; with "Moorea" in the Distribution).

FAMILY ODONTODACTYLIDAE

Odontodactylus brevirostris (Miers, 1884)

DISTRIBUTION. — Marquesas (Fatu Hiva) - *Sublittoral (49m).*

REFERENCES. — ***Odontodactylus brevirostris*** - MANNING, 1967b: 22, fig. 6-8 (Revision of the genus); 1995: 20, 82 (List & key). — MÜLLER, 1994: 50 (Syn.) - NEW MATERIAL - Coll. RV *Marara*, det. R.B. MANNING (Fatu Hiva MNHN Sto 1962; 49m).

FAMILY PSEUDOSQUILLIDAE

Pseudosquilla ciliata (Fabricius, 1787)

DISTRIBUTION. — Gambier (Mangareva); Marquesas; Society (Tahiti).

REFERENCES. — ***Pseudosquilla ciliata*** - NOBILI, 1907: 410 (Mangareva "Rikitea"). — SEURAT, 1934: 61 (Mangareva). — EDMONSON, 1921: 288 (Marquesas). — CHABOUIS L. & F., 1954: 92, unumbered fig. (French Polynesia). — MÜLLER, 1994: 72 (Syn.). — MANNING, 1995: 20, 111, pl. 20, 21, fig. 59a, 60a,b,e, 61-63 (List & syn.) - NEW MATERIAL - Coll. P. FROUIN, det. R.B. MANNING ("Mahaena" = Tahiti MNHN Sto 1958).

Pseudosquillisma oculata (Brullé, 1837)

DISTRIBUTION. — Society.

REFERENCES. — ***Pseudosquilla oculata*** - KEMP, 1913: 102 (Society Islands). — MÜLLER, 1994: 76 (Syn.). — ***Pseudosquillisma oculata*** - CAPPOLA & MANNING, 1995: 285 (New combination). — MANNING, 1995: 21 (List) - Not *Pseudosquilla oculata* - HELLER, 1865: 124 (see under *Raoulserenea ornata*).

Raoulserenea hieroglyphica (Manning, 1972)

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Pseudosquilla hieroglyphica*** Manning, 1972: 2, fig. 1 (Tahiti). — MÜLLER, 1994: 75 (Syn.). — ***Raoulserenea hieroglyphica*** - MANNING, 1995: 21, 116 (List & key; new combination).

Raoulserenea ornata (Miers, 1880)

DISTRIBUTION. — Society (Moorea, ?Tahiti) - *Littoral to sublittoral (31m).*

REFERENCES. — ***Pseudosquilla oculata*** - ? HELLER, 1865: 124 (Tahiti) ? non *P. oculata* (Brullé, 1837). — ***Pseudosquilla ornata*** - MIERS, 1880: 33, pl. 3, fig. 5, 6 (Syn.; ?Tahiti see remark). — SEURAT, 1934: 61 (HELLER's material). — MÜLLER, 1994: 77 (Syn.; Moorea in Distribution; up to 31m). — ***Raoulserenea ornata*** - MANNING, 1995: 21, 118, pl. 22, fig. 59b, 60c,d,f, 64 (List & key; new combination).

REMARK. — MIERS (1880: 34) writes under *Pseudosquilla ornata*: "I believe that the specimens from Tahiti, referred by HELLER (l.c.) to *P. oculata*, belong to this species, as the rostrum is described as 'vorn abgerundet;' and of the terminal post-abdominal segment he observes, 'gewahrt man auf der Oberfläche mehrere Längsleistchen, und zwar eine lange mittlere und zwei seitliche.'"

Raoulserenea n.sp. Manning & Caldwell in preparation

DISTRIBUTION. — Society (Moorea); Tuamotu (Mataiva).

REFERENCES. — ***Raoulserenea*** n.sp. - MANNING & CALDWELL, in preparation: coll. R. CALDWELL, Moorea; coll. M. MONTEFORTE, 23/05/1982, Mataiva, outer reef, intertidal, dead coral fragments, MNHN Sto 1964.

FAMILY TAKUIDAE

Mesacturus furcicaudatus (Miers, 1880)

DISTRIBUTION. — Tuamotu (Makatea, Mataiva).

REFERENCES. — ***Gonodactylus furcicaudatus*** - NOBILI, 1907: 410 (Makatea). — SEURAT, 1934: 61 (Makatea). — ***Mesacturus furcicaudatus*** - MONTEFORTE, 1984: 173, annex 1, tab. a (Mataiva). — MÜLLER, 1994: 50 (Syn.). — MANNING, 1995: 21, 119 (List & new family).

FAMILY CORONIDIDAE

Parvisquilla multituberculata (Borradaile, 1898)

DISTRIBUTION. — Society (Moorea).

REFERENCES. — ***Parvisquilla multituberculata*** - MANNING, 1978a: 16, fig. 8a-f (Moorea); 1995: 22 (List). — MÜLLER, 1994: 84 (Syn.).

FAMILY LYSIOSQUILLIDAE

Lysiosquillina sulcata (Manning, 1978)

DISTRIBUTION. — Society (Moorea).

REFERENCES. — ***Lysiosquilla sulcata*** - STEGER & BENIS-STEGER, 1988: 94 (Moorea). — MÜLLER, 1994: 89 (Syn.). — ***Lysiosquillina sulcata*** - MANNING, 1995: 22, 133, 134 (List & key; new combination).

Lysiosquillina maculata (Fabricius, 1793)

DISTRIBUTION. — Marquesas (Nuku Hiva); Society (Bora Bora, Moorea, Raiatea, Tahiti); Tuamotu (Mataiva, Toau) - *Littoral to sublittoral (28m).*

REFERENCES. — ***Lysiosquilla maculata*** - HELLER, 1865: 260, 265 (Tahiti; distribution table only). — BIGELOW, 1894: 508 ("Tawhae" = Taiohae, Nuku Hiva). — EDMONSON, 1921: 292 (Tahiti). — BOONE, 1934: 21-28, pl. 5-6 (Tahiti). — MANNING, 1967c: 103 (Tahiti; BOONE's material). — MANNING, 1978c: 3, fig. 1-3, 9 (Bora Bora, Nuku Hiva, Raiatea, Tahiti, Toau). — MONTEFORTE, 1984: 173, annexe I, tab. a (Mataiva). — DELESALLE, 1985: 288, 293 (Mataiva). — MÜLLER, 1994: 91 (Syn.). — ***Lysiosquillina maculata*** - MANNING, 1995: 22, 134, fig. 68c, 70a,b, 71a,b, 72a,b, 74-77, 78a, 80a (List & key; new combination) - NEW MATERIAL - Coll. & det. J. POUPIN, May 1997 (Moorea).

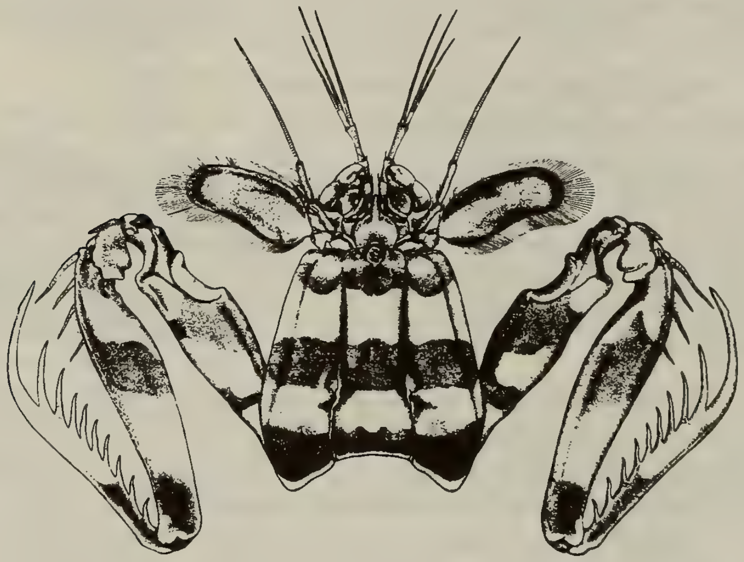

Figure 7 - *Lysiosquillina maculata* (Fabricius, 1793)
(Carapace, anterior appendages, and raptorial claws, from MANNING, 1995)

FAMILY NANNOSQUILLIDAE

Pullosquilla litoralis (Michel & Manning, 1971)

DISTRIBUTION. — Marquesas (Nuku Hiva); Society (Moorea).

REFERENCES. — ***Austrosquilla litoralis*** Michel & Manning, 1971: 237, fig. 1 (Nuku Hiva). — ***Pullosquilla litoralis*** - MANNING, 1978a: 19 (Moorea); 1995: 23 (List). — MÜLLER, 1994: 120 (Syn.).

Pullosquilla thomassini Manning, 1978

DISTRIBUTION. — Society (Moorea).

REFERENCES. — ***Pullosquilla thomassini*** Manning, 1978a: 20, fig. 9a-e (Moorea); 1995: 23 (List). — MÜLLER, 1994: 121 (Syn.).

FAMILY SQUILLIDAE

Alima alba (Bigelow, 1893)

DISTRIBUTION. — Society (Moorea).

REFERENCES. — ***Alima alba*** - SCHOTTE & MANNING, 1993: 577 (Syn.). — MANNING, 1995: 23 (List) - NEW MATERIAL - MANNING personal communication, in USNM collections, R. CALDWELL leg. 1980 (Moorea; in rubble, 1m).

Busquilla quadraticauda (Fukuda, 1911)

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Busquilla quadraticauda*** - MÜLLER, 1994: 135 (Syn.). — MANNING, 1995: 23, 170 (List & key) - NEW MATERIAL - Coll. P. FROUIN, det. R.B. MANNING (Tahiti MNHN Sto 1961; a juvenile).

Miyakea nepa (Latreille, 1828)

DISTRIBUTION. — Society (Tahiti).

REFERENCES. — ***Squilla nepa*** - HELLER, 1865: 124 (Tahiti). — SEURAT, 1934: 61 (HELLER's reference). — ***Oratosquilla nepa*** - MÜLLER, 1994: 167 (Syn.). — ***Miyakea nepa*** - MANNING, 1995: 25, 213, 216, pl. 37, fig. 130a,b, 131d,e, 132-134 (List & key; new combination).

REMARK. — MANNING (Personal communication) has examined HELLER's material from Tahiti in the Vienna Museum. It is labeled as taken by the *Novara* and is correctly identified.

Oratosquilla calumnia (Townsley, 1953)

DISTRIBUTION. — Marquesas (Eiao) - *Sublittoral (55m).*

REFERENCES. — ***Oratosquilla calumnia*** - MÜLLER, 1994: 161 (Syn.). — MANNING, 1995: 25, 220 (List & key) - NEW MATERIAL - Coll. RV *Marara*, 19/01/91, det. R.B. MANNING (Eiao MNHN Sto 1963; 55m).

FAMILY PROTOSQUILLIDAE

Echinosquilla guerinii (White, 1861)

DISTRIBUTION. — Marquesas (Nuku Hiva).

REFERENCES. — ***Gonodactylus guerinii*** - GRAVIER, 1928: 337, fig. 1-3 (Nuku Hiva). — BIGELOW, 1931: 139 (Syn.). — ***Echinosquilla guerinii*** - MÜLLER, 1994: 61 (Syn.). — MANNING, 1995: 21 (List).

ADDITIONS

Additions or modifications to POUPIN (1996a) checklist of Astacidea, Palinuridea, Anomura and Brachyura are given here. They mostly come from revised or unstudied RV *Marara* collections. One Polychelidae and two Calappidae are identified from material recently collected in the Marquesas (RV *Alis*, August/September, 1997), and three crabs Cryptochiridae are reported from re-examination of MNHN collections (det. R.K. KROPP).

FAMILY ENOPLOMETOPIDAE

The *Enoplometopus* sp. nov. from the Marquesas (POUPIN *et al.*, 1990: 16, pl. 3c; POUPIN, 1996a: 8; 1996b: 12, pl. 5h) has been recognised in Taiwanese waters and submitted for description by CHAN & YU (1998).

FAMILY POLYCHELIDAE

Stereomastis phosphorus (Alcock, 1894), a common Indo-Pacific species, has been collected during the RV *Alis* Marquesas Expedition (Nuku Hiva, 405m).

Figure 8 - RV *Alis*, 28.4 m long, lateral view
Crustacea have been recently collected by this vessel around the Marquesas, between 20-1000m (MUSORSTOM 9 Marquesas Expedition, August 18th - September 11th, 1997)

FAMILY PALINURIDEA

Palinuridae could now include, *Panulirus albiflagellum* Chan & Chu, 1996. CHAN & CHU (1996: 381) mentioned that *Panulirus longipes femoristriga* (A. Milne Edwards, 1868), reported in French Polynesia by GEORGE (1972), is "without cross-bands on the antennular flagella" and could be *Panulirus albiflagellum*".

FAMILY DIOGENIDAE

Six new records of *Calcinus* are given by POUPIN (1997): *Calcinus gouti* Poupin, 1997; *C. haigae* Wooster, 1984; *C. imperialis* Whitelegge, 1901; *C. isabellae* Poupin, 1997; *C. orchidae* Poupin, 1997; and *C. vachoni* Forest, 1958. Additionally, three more new *Calcinus* have been submitted for publication (POUPIN & MCLAUGHLIN, in press).

A large specimen of *Dardanus sanguinocarpus* Degener, in Edmonson 1925 has been collected at Eiao, during the RV *Alis* Marquesas Expedition. Coloration of this specimen agrees very well with the illustration given in HOOVER (1997; det. P. MCLAUGHLIN).

FAMILY PAGURIDAE

From unstudied RV *Marara* material, three species has been identified by P. MCLAUGHIN: *Catapagurus ensifer* Henderson, 1893 (Eiao; 54m), *Nematopagurus* cf. *spinulosensoris* McLaughlin & Brock, 1974 (illustrated in POUPIN, 1996b: 18, pl. 8f), and *Pylopaguropsis lewinsohni* McLaughlin & Haig 1988 (Fangataufa, Moruroa; 110-190m). Moreover, *Solitariopagurus* sp. nov. (POUPIN, 1996a: 96) is now described under *Solitariopagurus triprobolus* Poupin & McLaughlin, 1996 (illustrated in POUPIN, 1996b: 18, pl. 8g).

FAMILY PARAPAGURIDAE

From RV *Marara* collections (Moruroa, 200m) *Oncopagurus oimos* sp. nov. is described by LEMAITRE (1998).

FAMILY GALATHEIDAE

Two galatheids, *Munida distiza* Macpherson, 1994 (Moruroa; 290m) and *Munida elegantissima* de Man, 1902 (Eiao, 55m), have been recognised during the last RV *Marara* campaigns (illustrated in POUPIN, 1996b, pl. 10b, c, pl. 10d).

FAMILY ALBUNEIDAE

From RV *Marara* collections *Albunea* sp. cf. *symnysta* (Linné, 1758) (Eiao, Fatu Hiva; 100m) is reported and illustrated in POUPIN (1996b: 26, pl. 12c).

FAMILY CALAPPIDAE

Calappa sp. nov. in POUPIN (1996a: 97; 1996b: 30, pl. 14d) is now described under *Calappa sebastieni* Galil (1997a). Therefore, from RV *Alis* Marquesas collections, two other Calappidae are tentatively attributed here to *Calappa* aff. *gallus* (Herbst, 1803) (Hiva Oa, 98-100m; st. DW1210) and *Mursia* aff. *spinimanus* Rathbun, 1906(Hatutu, 163-245m; st. DW1287).

FAMILY PARTHENOPIDAE

Attention is drawn to *Parthenope contrarius* (Herbst, 1796) illustrated in POUPIN (1996b: 32, pl. 15d), and again collected during the RV *Alis* Marquesas Expedition. This material seems to be similar to *Lambrus* (*Rhinolambrus*) *longispinis* Miers, reported and illustrated from Hawaii by TINKER (1965: 88, pl. 32). Revision of that material is necessary for a correct determination.

FAMILY GONEPLACIDAE

The *Intesius* sp. nov. illustrated in POUPIN *et al.* (1990: 19 pl. 3a) and POUPIN (1996b: 34, pl. 16e) is proposed for publication by DAVIE (1998).

FAMILY XANTHIDAE

Alainodaeus nuku Davie, 1997 has been described from RV *Marara* unstudied collections (Eiao, Nuku Hiva, Raevavae; 100-400m).

FAMILY TRAPEZIIDAE

MNHN material, collected by P. LABOUTE in the Tuamotu (Tikehau, 50/60m, in *Stylaster* coral) has been described under *Hexagonalia laboutei* Galil, 1997b. Other trapeziids collected during RV *Marara* campaigns or deposited in MNHN collections have been studied by CASTRO (1997a, b) with the following species added to the fauna: *Tetralia fulva* Serène, 1984; *Tetralia rubridactyla* Garth 1971; *Tetralia vanninii* Galil & Clark, 1988; *Trapezia globosa* Castro 1997b; and *Trapezia lutea* Castro, 1997a. Moreover, CASTRO has removed three trapeziids from the regional fauna: *Tetralia glaberrima* (Herbst, 1790) whose records are attributed either to *T. cinctipes* Paulson, *T. fulva* Serène, or *T. vanninii* Galil & Clark; *Trapezia formosa* Smith, 1869 re-identified to *Trapezia globosa* Castro 1997b; and *Trapezia septata* Dana, 1852, re-identified to *Trapezia areolata* Dana, 1852.

FAMILY CRYPTOCHIRIDAE

MNHN material from Marutea South, attributed by NOBILI (1907) to *Cryptochirus coralliodytes* Heller, 1861, has been re-examined by KROPP (Personal communication). It is re-identified to *Lithoscapus paradoxus* A. Milne Edwards (1862) and *Sphenomaia pyriforma* (Edmonson, 1933). These observations throw a doubt on the effective presence of *Cryptochirus coralliodytes* Heller, 1861 in French Polynesia (*cf.* records from Marokau by NOBILI, 1907, and Makatea by SENDLER, 1923). From RV *Marara* collections (Fatu Hiva, Marquesas) KROPP has also identified *Utinomiella dimorpha* (Henderson, 1906).

Table 1 - French Polynesian shrimps
number of species by Infra-Order and Family

INFRA-ORDER	FAMILY	SPECIES
Dendrobranchiata		**25**
	Aristaeidae	3
	Benthesicymidae	3
	Penaeidae	12
	Solenoceridae	3
	Sicyoniidae	1
	Luciferidae	2
	Sergestidae	1
Stenopodidea		**2**
	Stenopodidae	2
Caridea		**170**
	Nematocarcinidae	2
	Atyidae	5
	Oplophoridae	10
	Stylodactylidae	1
	Rhynchocinetidae	3
	Gnathophyllidae	1
	Anchistioididae	1
	Hymenoceridae	1
	Palaemonidae	46
	Alpheidae	57
	Hippolytidae	10
	Processidae	2
	Pandalidae	29
	Thalassocarididae	1
	Crangonidae	1
Thalassinidea		**9**
	Axiidae	3
	Callianassidae	4
	Callianideidae	1
	Thomassiniidae	1
Total		**205**

DISCUSSION

From this compilation 205 shrimps and 26 Stomatopoda are reported from French Polynesia (Tab. 1 & 2). Within the shrimps Caridea alone are represented by 170 species (83 % of the shrimps) mainly Alpheidae (57 species), Palaemonidae (46 species), and Pandalidae (29 species).

Table 2 - French Polynesian Stomatopoda
number of species by Family

Stomatopoda		**26**
	Indosquillidae	1
	Gonodactylidae	8
	Odontodactylidae	1
	Pseudosquillidae	5
	Takuidae	1
	Coronididae	1
	Lysiosquillidae	2
	Nannosquillidae	2
	Squillidae	4
	Protosquillidae	1

If the previous list of French Polynesian Astacidea, Palinuridea, Anomura, and Brachyura is considered (POUPIN, 1996a; with above additions), the total number of Decapoda and Stomatopoda comes to 757 species. The number of species by Infra-Order is summarized in Table 3 where it clearly appears that Brachyura alone represents almost 50 % of the species.

Table 3 - French Polynesian Decapoda and Stomatopoda
number of species by Infra-Order

INFRA-ORDER	NUMBER OF SPECIES	PERCENTAGE (%)
Dendrobranchiata	25	3,2
Stenopodidea	2	0,3
Caridea	170	22,5
Thalassinidea	9	1,2
Astacidea	4	0,5
Palinuridea	19	2,5
Anomura	126	16,6
Brachyura	377	49,8
Stomatopoda	26	3,4
Total	**758**	100 %

Although drawn from more than a century of research, this report is only a first step in the elaboratation of a comprehensive fauna of French Polynesia. Increased effort in collection is needed as well as careful revision of many genera.

Few groups have been relatively well studied. They include: Pandalidae (CROSNIER, 1986a,b, 1988b; CHAN & CROSNIER, 1991, 1997); Palinuridea and Coenobitidae (see POUPIN, 1996a), Diogenidae of the genus *Calcinus* (POUPIN, 1997; POUPIN & MCLAUGHLIN, in press); Parapaguridea (LEMAITRE, 1994, 1998), deep Galatheidae (MACPHERSON & DE SAINT LAURENT, 1991), Homolidae (GUINOT & RICHER DE FORGES, 1995); Geryonidae (MANNING, 1992, 1993b); Etisinae and Chlorodiinae (see POUPIN, 1996a); Trapeziidae (ODINETZ, 1983, 1984; CASTRO, 1997a, b; GALIL, 1997b); and Ocypodidae (*cf.* POUPIN, 1996a, 1997b).

A lot of groups need further researches. Freshwater Decapoda have been intensively collected (MARQUET, 1988, 1991, 1993; KEITH & VIGNEUX, 1997) but revision of the *Macrobrachium* is necessary to establish the status of one to three new species (*cf.* under *Macrobrachium latimanus*).

Alpheidae, representing the bulk of the shrimps, are almost exclusively known from the collections made in 1954 in the Society Islands by A.H BANNER (BANNER & BANNER, 1967). It is regrettable that all this material has been destroyed in the Hawaii laboratory fire of 1961 (see Caridea section), thus excluding any revision of the collection and limiting BANNER & BANNER (1967) to a documented list written from a draft manuscript and field notes, without illustrations or key.

Pontoniinae, although represented by scores of species, are certainly under-estimated. Without particular effort, field collections realised by the present author and determined by A.J. BRUCE have added 10 more species to this list, and several world-wide distributed species, such as *Gnathophylloides mineri* Schmitt, 1933 (Indo-Pacific and Atlantic), are still not recorded in French Polynesia although it is inconceivable that they are not occuring there.

The Infra-Order Thalassinidea has only 9 species. This low figure is undoubtedly the result of the burrowing mode of life of these species, and the resulting difficulty to collect them. Revision of the Indo-Pacific Upogebiidae (SAKAI, 1982) does not mention a single French Polynesian member. Axiidae are represented by only 3 species, whereas SAKAI & DE SAINT LAURENT (1989) report 9 species around Hawaii. Nevertheless, we know that the number of species is usually greater in French Polynesia than in Hawaii (*cf.* POUPIN, 1996a: 78).

A large RV *Marara* collection of Portunidae is still under study by MOOSA & CROSNIER and will include several news records (*Brusinia*, *Portunus*, and *Thalamita* spp.).

To conclude this brief overview of groups that need further research, Stomatopoda appear obviously under-represented. In New Caledonia, investigations in the lagoon conducted by means of a dredge (RICHER DE FORGES, 1991) have boosted the number of Stomatopoda from 10 to 69 (MOOSA, 1991). French Polynesian lagoons are usually inadequate for navigation. However, if dredges were operated by means of small boats, we could expect a significant increase of number of Stomapoda, as well as for many Decapoda (Majidae, Portunidae, Xanthidae...).

A special mention must be given here to the recent MUSORSTOM 9 Marquesas Expedition, August 18th - Septembre 11th, 1997, RV *Alis*. During that cruise, dredge and beam-trawl were operated between 20-1000m, and a large collection of Crustacea was realised. This material, deposited at the MNHN, is still unstudied. However, from field notes taken by the present author, it appears that this collection will bring a minimum of 60 new records. These include bathypelagic shrimps (Aristeidae, Benthesicymidae, Solenoceridae, Sergestidae), Stenopodidea (at least three species), lobsters (Scyllaridea, Axiidae), Crangonidea, Diogenidae (a new *Ciliopagurus*), Parapaguridea, Galatheidea (*Munida* spp.), Chirostylidae (first record of an *Uroptychus* sp.), Dromiidae, Dorripidae (first report of the family), Calappidae, Leucosiidae (at least five additional species), Majidae, Portunidae, Xanthidae, and Palicidae (first report of the family). This estimation is reported on figure 9 where evolution of number of species within the years is illustrated. Number of Polynesian Decapoda and Stomatopoda will thus exceed 800 species. Moreover, it appears that researches conducted after 1980 (CRIOBE Moorea studies and RV *Marara* campaigns) have generated 322 new records, *i.e.* an increase of 74 % ! If this effort was continued in the future, it is to be expected that regional fauna will reach the level of a thousand species.

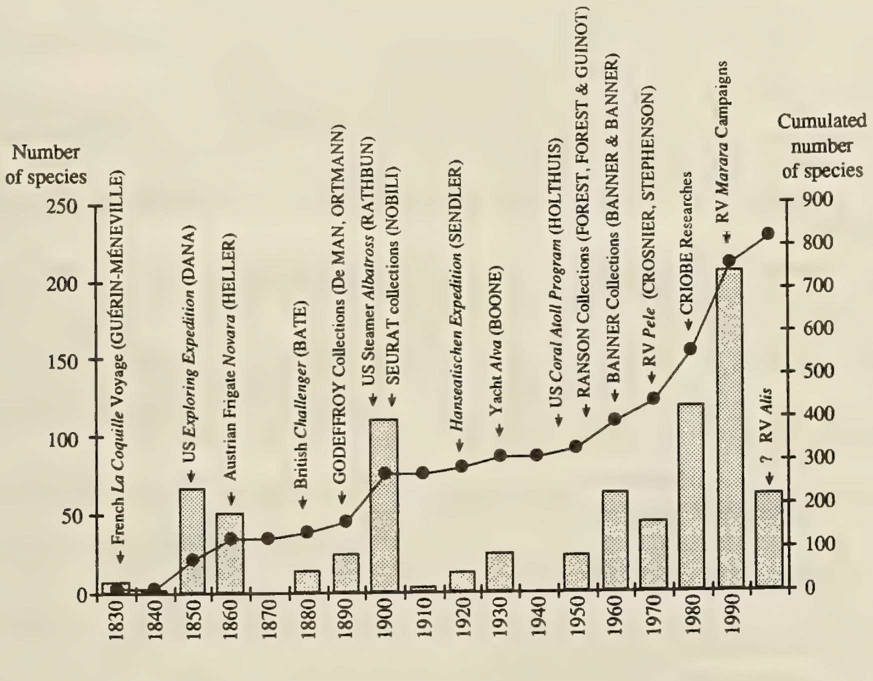

Figure 9 - Historical of collections of the French Polynesian Decapoda and Stomatopoda Number of species, and cumulated number of species, recorded each 10 years, with indication of main episodes in collections

In the present state of knowledge, biogeographical consideration are rather hazardous for most of the groups. The main trend, as generally admitted, would be towards a decreasing biodiversity from Indonesia and Australia to French Polynesia. For example, BRUCE (1990: 13) mentioned 168 Australian pontoniins for only 36 in French Polynesia. However, this difference is probably amplified by imperfection of our data, and could be reduced when pontoniids are better studied in French Polynesia. In fact, for genera that have been well studied, biodiversity appears only slighly lower, or even greater, than in western Pacific. For example *Plesionika* count 21 species in French Polynesia *vs* 29 in western Pacific (CHACE, 1985) or 26 around Taiwan (CHAN, personal communication). Hermit crabs of the genus *Calcinus* were cited as an example of low diversity in French Polynesia by POUPIN (1996a), with only 10 species *vs* 23 in Indonesia. However, after more collections and revision of the genus (see above) the balance is now 18 *vs* 23 and biodiversity of Polynesian *Calcinus* appears even greater than in Australia (17 species in MORGAN, 1991). The same observation is verified after more collections and re-examination of the genus *Trapezia* by CASTRO (1997a, b) who records 14 Polynesian species *vs* only 11 in New Caledonia and CASTRO concludes (1997b: 131): "The decrease in species diversity that is expected as one moves eastward from areas of high diversity in the western Pacific is not observed in trapeziids".

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ACKNOWLEDGEMENT

I am most grateful to the following people for their help and support during this work.

Determinations published here for the first time have been made by A. CROSNIER (Aristaeidae, Penaeidae, Solenoceridae, Sicyoniidae, and Oplophoridae), T. KOMAI (Nematocarcinidae), A.J. BRUCE (Pontoniinae, and Hippolytidae), P. NOEL (Processidae), P.A. MCLAUGHLIN (Paguridae), R.K. KROPP (Cryptochiridae), and R.B. MANNING (Stomatopoda). F.A. CHACE, T. KIKUCHI, and B. KENSLEY solved problems encountered with old records of the Oplophoridae, Sergestidae, and Luciferidae. Dr. L.B. HOLTHUIS kindly gave information about two old Institutions, GODEFFROY and OTAGO Museums, and P. FROUIN sent several interesting shrimps and stomatopoda collected during his thesis at ORSTOM Tahiti research center.

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ATOLL RESEARCH BULLETIN

NO. 452

INVESTIGATIONS ON THE SOFT BOTTOM BENTHOS IN A SOUTHWEST PACIFIC ATOLL LAGOON (UVEA, NEW CALEDONIA)

BY

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ISSUED BY
NATIONAL MUSEUM OF NATURAL HISTORY
SMITHSONIAN INSTITUTION
WASHINGTON, D.C., U.S.A.
SEPTEMBER 1998

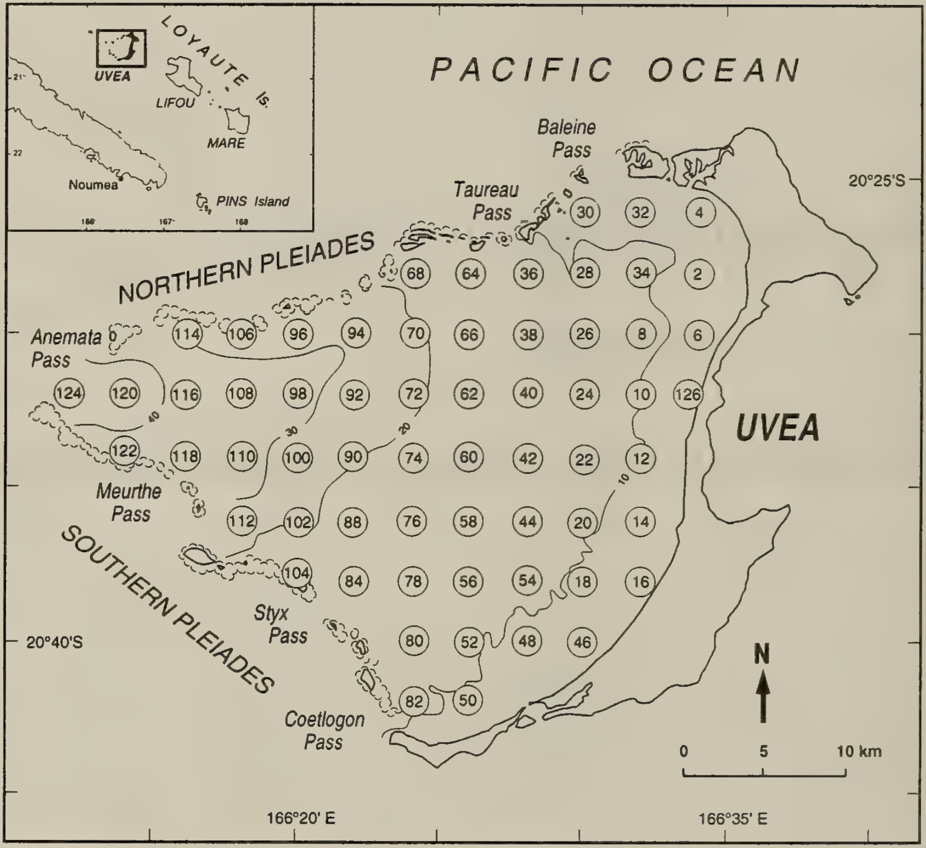

Figure 1. Location of the stations in Uvea Atoll.

INVESTIGATIONS ON THE SOFT BOTTOM BENTHOS IN A SOUTHWEST PACIFIC ATOLL LAGOON (UVEA, NEW CALEDONIA)

BY

Claire GARRIGUE[1], Jacques CLAVIER[2], and Christophe CHEVILLON[1]

ABSTRACT

Microbenthos and macrobenthos were quantitatively studied at 62 stations distributed regularly over the Uvea Atoll lagoon (850 km²). Sampling was performed using both SCUBA and a 0.1 m² Smith McIntyre grab. Mean estimates of ATP, chlorophyll *a* and phaeopigments were 297.3 ng/cm², 77.01 mg/m² and 35.28 mg/m² respectively. The mean macrobenthic biomass was 4.14 gAFDW/m² of which the macrophytobenthos accounts for 39%. The benthic biomass decreased from the coast to the deepest parts of the lagoon. Macrophytes were most abundant in the coastal area and became progressively scarcer with increasing depth. By comparison, sessile species dominated on hard substrates in intermediate and deep zones. The abundance of the surface-deposit feeder group, that dominated the trophic structure of zoobenthos (33% of the macrofauna biomass), could be explained by a microphytic biomass six times higher than macrophytobenthic one in terms of carbon. Carnivores (32%) were mainly represented by necrophagous species, and filter-feeders (27%) by bivalves. Herbivores were rare. Four main benthic communities were identified on the basis of their macrobenthic assemblages using a Detrended Correspondence analysis. They corresponded to (1) a coastal zone, with the highest mud percentage in sediments, (2) an intermediate zone, with moderate depth and dominated by hard substrates, (3) a back reef zone, with thick sand layers, and (4) a deep zone dominated by hard substrates. Relative distribution of the trophic groups varied according to the different zones and suggests distinct functional characteristics for the different benthic assemblages. From a biogeographic point of view, this study highlighted the richness of the Uvea Atoll lagoon in terms of benthic species and biomass, compared to other central Pacific atoll lagoons.

INTRODUCTION

In coral reef areas most studies target community structure of the hard bottoms, focusing on the reef itself and the external slope surroundings. However, the soft bottoms, predominantly made up of carbonate sand and gravel, cover large surfaces and constitute the habitat of numerous organisms that are important in the coral ecosystem and cannot be neglected (Alongi, 1990 ; Jones et al., 1990). Of the studies

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Manuscript received 25 March 1998; revised 1 July 1998

carried out on atolls, very few have investigated soft-bottom benthic communities of the lagoon.

Of the few atolls in the southwest Pacific several belong to the Territory of New Caledonia : Uvea, Huon and Surprise in the north, and Chesterfield and Bellona in the west. Previous scientific data on these atolls are scarce. Some geology, geomorphology and sedimentology reports, and some descriptions and faunistic inventories can be found (Richer de Forges and Bargibant, 1985 ; Clavier and Garrigue, 1990 ; Richer de Forges, 1991; Chevillon et al., 1992 ; Chevillon, 1996), but the characteristics and communities of the soft bottoms of the lagoon are unknown.

In the present study we test the hypothesis that richness in terms of taxa and biomass is greater than in that found in central and eastern Pacific islands according to the biogeographic species dispersion theory (Eckman, 1953). More over due to the physical structure of this atoll situated on the slope of the lithospheric bulge (Dubois et al., 1977) we hypothesize that the spatial distribution of organisms will be different than that observed in a typical atoll. As the test, the composition, structure and biomass of the macrobenthos will be used. Other biological parameters such as ATP and photosynthetic pigment content in the sediments will be estimated in order to evaluate the quantity of micro + meiobenthos and microphytobenthos, respectively.

MATERIAL AND METHODS

a. Study site

Uvea Atoll and its ''satellite'', Beautemps-Beaupré atoll, constitute the northern part of the Loyalty Archipelago, in the north east of New Caledonia. Uvea lagoon forms a vast equilateral triangle the sides of which are about 35 nautical miles long (Fig.1). It is bounded by the Northern and Southern Pleiades, a group of low coral islands set on top of a discontinuous barrier reef, and eastward by the main calcareaous island of Uvea. The lagoon is open to the ocean by numerous passes. Due to its situation on the slope of the lithospheric bulge (Dubois et al., 1977) the bottom of the lagoon slopes slightly westward reaching a maximum depth of about 40 m near Anemata Pass. The mean depth is 19 m. Hard susbtrates consist of a fairly smooth limestone tab with scattered small coral structures. Sediments are always of a light colour, have a high carbonate content, and a low percentage of mud. Sediment thickness is generally low with a mean depth of 5.4 cm and an average of 3.83% organic matter content (Chevillon et al., 1992 ; Chevillon, 1996).

The benthos was sampled from the *R.V. ALIS* during two cruises (August and September) in 1991. The zones investigated zone cover an area of 850 km². The study focused on lagoon bottoms, except for coral structures that represent only a small part of the total area (<5%). Sixty-two sampling stations were distributed regularly over a 2 nautical mile grid (Fig.1). Three benthic compartments were surveyed : the "small food web" (meio + microbenthos), the microphytobenthos and the macrobenthos (plant and animal benthos).

b. Sampling and analysis

Meio and microbenthos. ATP (Adenosin Triphosphate) is considered to be an estimate of living or metabolically active biomass (Pamatmat et al., 1981). We assumed that ATP is proportional to the "small food web" biomass (Chardy and Clavier, 1988). For convenience, we grouped under this category all the organisms smaller than 2 mm. This category included that part of the macrobenthos retained by a 1 mm mesh sieve but passing through a 2 mm mesh sa well as the meiobenthos and the microbenthos. Larger organisms can easily be seen and were removed from sediment cores prior to ATP extraction. Five 5.31 cm² cores were randomly collected by SCUBA at each sampling station except stations 112 and 124 where the sediment was too thin. On collection the top cm of each core was immediately and carefully separated. Extraction was accomplished with 10 ml of boiling NaHCO3 solution (0.1 M) (Bancroft et al., 1976), the extract was frozen for later analysis using the bioluminescence method (Strehler and Totter, 1952). The results were expressed in ng/cm².

Microphytobenthos. Biomass was indirectly assessed through measurement of sedimentary photosynthetic pigments, chlorophyll *a* and phaeopigments. Five 5.31 cm² cores were hand-collected by SCUBA at each sampling station. The top cm was carefully separated and frozen in darkness. According to the methods of Garrigue and Di Matteo (1991), the samples were later lyophilised and pigments were extracted with 90% acetone during an 18 to 24 h period. After filtration of the extract, optical densities were assessed using a spectrophotometer at 750 and 665 nm, both prior to and after acidification with 0.5N HCl. Lorenzen's (1967) equations were used to calculate functional chlorophyll *a* and phaeopigment concentrations. The results were expressed in mg/m².

Macrobenthos. Macrofauna (2 to 20 mm) and macroflora were sampled using a Smith McIntyre grab weighted down with an additional 60 kg of lead ballast. This gear collects the sediment from a 0.1 m² area. The depression left in the sediment is rectangular in shape, while the bite profile is elliptical with a maximal depth of 13 cm (Clavier, 1982). Zones with sediment layers greater than 10 cm were present in only 15% of the lagoon area, whereas thick sediment areas (>20 cm), where large organisms can be deeply burrowed, were seldom found and were mainly restricted to the north-western part of the lagoon (Chevillon et al., 1992). Thus, we consider that our sampling collected most of the benthic organisms and that biomass values are representative of the lagoon. A sampling unit of 1 m² area was collected using a 0.1 m² grab dropped ten times. The boat was anchored at the bow and was able to swing under the influence of wind. The 10 grab samples from the same station were combined and passed through 20, 5 and 2 mm mesh stacked sieves. On board, organisms were separated from the substrate, sorted by major taxonomic groups and preserved in 10% formalin neutralised with borax.

Epibenthic megafauna (> 20 mm) and large macrophytes were sampled using SCUBA. A 50 m rope was uncoiled on the bottom. The divers, using a 1 m pole, collected all large living organisms found to 1 m on each side of the rope, except those associated with coral structures. The resulting total area covered 100 m². Samples were frozen. In the laboratory, taxonomic determinations were carried out as precisely as possible using the available literature. The results per station have been expressed as number of taxa per sampling station and as densities (number of individuals per m² for each identified taxon). Dry weights were measured following oven-drying (60°C) to constant weight, and ash weight was measured after combustion at 550°C for 3 h. The ash free dry weight is the difference between these two values. Macrobenthic biomass was expressed in grams of ash free dry weight per m² (gAFDW/m²). These methods are similar to those used by Chardy et al. (1988) and Chardy and Clavier (1988) for the study of New Caledonia's SW lagoon macrobenthos.

The macrobenthic biomass was assessed for the whole lagoon and for each community. Calculations were first carried out on pooled data and then by taxonomic group. We considered the following categories : macrophytes, gastropods, bivalves, sponges, crustaceans and echinoderms. Other taxa were grouped as "others". Data were then organised by trophic groups according to the Chardy and Clavier (1988) classification, i.e. primary producers (macrophytes) (PP); suspension-feeders (S) mainly comprising sponges and filter bivalves; "deposit-feeders" divided into surface deposit-feeders (SDF) that take their food from the water-sediment interface, and deposit-swallowers (DS) that ingest the sediment, herbivores (H) feeding on macrophytes ; and carnivores (C) comprising both predators and necrophagous species.

c. Data analysis

At the same time as the epibenthic megafauna sampling, the hard bottom cover was estimated at each station with a 10% precision according to the number of 0.1 m² grabs that were free of sediments. Because samples used for ATP and photosynthetic pigments measures were only taken from soft sediments, the results were amended to account for the percentage of hard bottom cover. Therefore the values calculated for ATP and photosynthetic pigments are over-estimated as meio, microbenthos or microphytobenthos were not sampled from hard substrate.

In order to use the floral and faunal data, the densities of the taxa were coded into 5 classes, prior to analysis (Chardy et al., 1988). We omitted 148 taxa that were recorded only once or twice in our sampling, except those with more than 3 ind/m². A data matrix was then subjected to an ordination in reduced space in order to (1) identify the main benthic communities and to (2) determine the relationships between communities and environmental parameters. We used the "detrended correspondence analysis" (DECORANA), a variant of reciprocal averaging described by Hill (1979) and Hill and Gauch (1980). This method, previously used to define benthic assemblages (Marchant, 1990 ; Alongi and Christoffersen, 1992), allows the horseshoe effect to be avoided (Gauch, 1982). Stepwise multiple linear regression between stations (dependent variable) and environmental parameters (predictor variables) (Sokal and Rohlf, 1981) was then applied to interpret this distribution. Means of the biotic parameters (ATP and photosynthetic pigments) were calculated for each community. The homogeneity of means was tested using ANOVA and an *a posteriori* test (LSD) after verification of the normality of data (Shapiro and Wilk, 1965) and homogeneity of variances (Hartley, 1962), was performed.

RESULTS

a. Micro and meiobenthos and microphytobenthos.

The contents in the top cm of sediment for these 3 parameters are presented in Table 1. They are not evenly distributed within the lagoon ; the highest concentrations were observed on the eastern part of the lagoon and the lowest concentrations occurred near the Southern Pleiades.

Table 1. Mean and range of biological parameters (S.E. = standard error ; N = number of samples). ATP is expressed in ng/cm²; Chlorophyll *a* and Phaeopigments are expressed in mg/m².

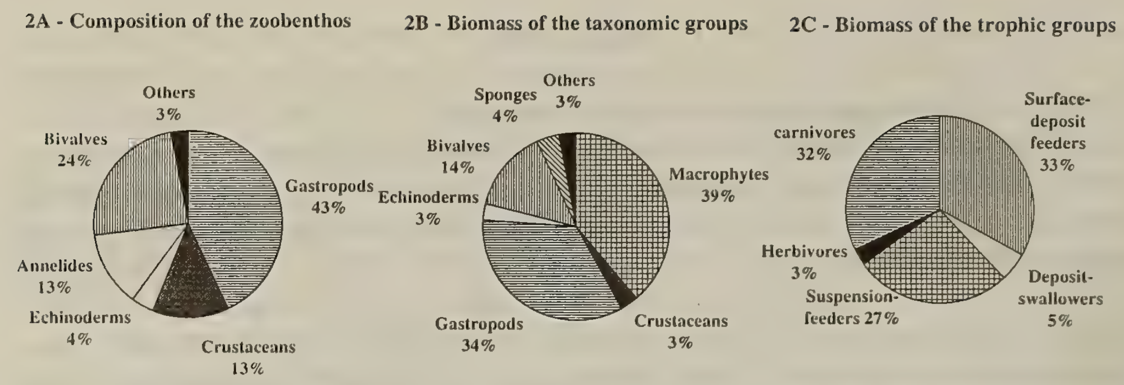
Biological parameters	Range (min. - max.)	Mean	S.E.	N
ATP	5.0 - 620.5	297.3	21.5	60
Chlorophyll *a*	2.19 - 267.80	77.01	6.09	60
Phaeopigments	1.69 - 86.97	35.28	2.96	60
Number of taxa per sampling station	0 - 89	27.56	1.65	62
Biomass	0 - 63.48	4.14	1.03	62
Macrophytobenthic biomass	0 - 49.09	1.63	0.81	62
Macrozoobenthic biomass	0 - 14.40	2.51	0.32	62

For the correlation between these parameters and the environmental ones, see Table 2.

b. Macrobenthos.

Numerical analysis of taxa. A total of 3699 individuals from 341 taxa (22 flora and 319 fauna) were identified in the Uvea Lagoon (Clavier et al., 1992). The number of taxa per sampling station and the densities are in Table 1. These two parameters follow a decreasing gradient east-west, from Uvea Island to Anemata Pass. The correlation with the environemental parameters are presented in Table 2. Mean diversity (Shannon and Weaver, 1949) is H'=3.96 bits/ind (S.E.=0.10) and equitability (Pielou, 1969) is E=0.87 (S.E.=0.01). The distribution of zoological groups is presented in Figure 2A.

Biomass. The mean biomass of the macrobenthos is 4.14 gAFDW/m² (S.E.=1.03 ; N=62). The plant matter, which accounts for 39% of this biomass (Table 1), is mainly dominated by green algae (85%) and Cyanophyceae (14%). The macrofauna biomass is dominated by molluscs (Fig.2B), in particular gastropods (77% of macrofauna biomass). The distribution of the macrobenthic biomass in the lagoon follows a decreasing gradient from east to west. A high macrozoobenthic biomass in the western part of the Northern Pleiades is due to the presence of a thick sediment area.


2A - Composition of the zoobenthos

2B - Biomass of the taxonomic groups

2C - Biomass of the trophic groups

Figure 2. Composition and biomass of the benthos

While the high macrophytobenthic biomass in the centre of the lagoon, is a result of the high abundance of a cushion-shaped *Cyanophyceae spp.* at station 90. Animal biomass is significantly correlated with depth, and plant biomass with mud percentage (Table 2).

Table 2. Relations between biological parameters and environmental parameters (ATP in ng/cm² ; Chlorophyll *a* and Phaeopigments in mg/cm² ; Density in ind/m² ; Biomass in gAFDW/m² ; Mean grain size in mm ; % hard bottom = hard bottom cover percentage ; Depth in m ; Sediment thickness in cm ; % mud = percentage of grain size < 63 µm, r = coefficient of correlation, *P*= probability as follows : * : *P*<0.05, ** : *P*<0.01, ns : not significant).

	Mean grain size		% hard bottom		Depth		Sediment thickness		% mud	
	r	*P*	r	*P*	r	*P*	r	*P*	r	*P*
ATP	0.22	ns	-0.75	**	-0.20	ns	0.39	**	0.10	ns
Chlorophyll *a*	-0.20	ns	0.29	*	-0.02	ns	-0.17	ns	0.09	ns
Phaeopigments	-0.05	ns	0.42	**	-0.07	ns	-0.35	**	0.08	ns
Number of taxa per sampling station	0.36	**	-0.49	**	-0.50	**	0.35	**	0.30	*
Density	0.25	ns	-0.32	**	-0.47	**	0.15	ns	0.21	ns
Macrophytobenthic biomass	0.08	ns	0.06	ns	-0.23	ns	-0.08	ns	0.34	**
Macrozoobenthic biomass	0.04	ns	-0.22	ns	-0.36	**	0.02	ns	0.17	ns

Trophic structure. In the Uvea Lagoon, macrobenthic biomass is dominated by deposit-feeders (0.95 gAFDW/m² ; S.E.=0.18), particularly by surface deposit-feeders (Fig.2C). The gastropod *Cerithium sp.* (cf. *tenuifilosum*) represents more than 50% of the latter biomass. The dominant species of deposit-swallowers are the holothurians *Halodeima atra* and *Microthele nobilis* (95% of the total biomass). The second trophic group in the lagoon are carnivores (0.79 gAFDW/m², S.E.=0.13), dominated by necrophagous species (gastropods and pagurid crustaceans). Suspension-feeders (0.66 gAFDW/m², S.E. 0.17) include mainly bivalves (68%) and sponges (21%), the latter sessile species are found mostly on hard substrates. Bivalves comprise both scattered large species (*Trachycardium enode* and *Fimbria fimbriata)* and smaller but more abundant species (*Timoclea* [*Glycydonta*] *marica*, *Lunulicardia sp.*, *Circe sp.* and *Fulvia sp.*). Herbivores are unimportant (0.07 gAFDW/m², S.E.=0.02) comprising mainly three gastropod species (*Chrysostoma paradoxum*, *Monilea nucleus* and *Turbo chrysostoma*).

Identification of benthic communities. The results from the detrended correspondence analysis are presented in Figure 3. Axis 1 is significantly correlated to hard bottom cover percentage, depth and mean grain size while axis 2 is only significantly correlated to depth and sediment thickness (Table 3).

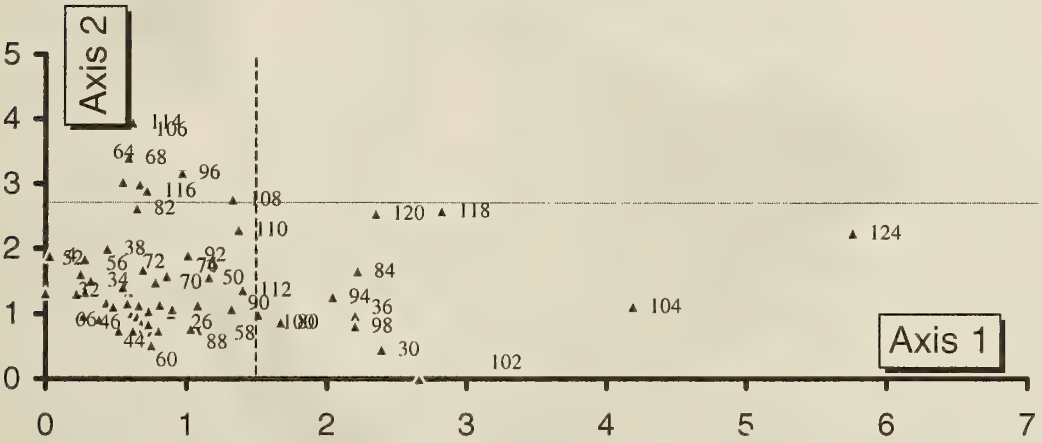


Figure 3. Results of the detrended correspondence analysis

In both cases predictor variables explain more than two thirds of the variance. Comparison of station distributions in the first factorial plane and their geographic positions allows four main groups to be identified (Figs. 3 and 4).

Table 3. Stepwise regression between station co-ordinates according to DECORANA analysis and environmental parameters. Only the parameters accepted by the regression are presented with their coefficient and t value. ** P< 0.01, r² is the coefficient of determination.

	Parameters	Coefficient	*t*	r²
Axis I	Hard bottom cover percentage	0.015	6.30 **	
	Depth	0.048	6.28 **	
	Mean grain size	0.099	4.57 **	0.736
Axis II	Sediment thickness	0.058	8.47 **	
	Depth	0.037	5.60 **	0.680

Furthermore, the joint increase of station co-ordinates along the two axes corresponds to a depth gradient related to the distance from the Uvea coast line. Each group can be distinguished by the characteristics of the environmental and biotic parameters (Table 4).Group I corresponds to shallow areas, with a relatively thin layer of medium to coarse sand. Group II mostly corresponds to hard substrates at medium depths; when present, the sediment consists of very coarse sand. Group III also corresponds to intermediate depths but with a relatively thick medium-to-coarse sand cover. Lastly, Group IV corresponds to deep hard bottoms almost baren of sediments.

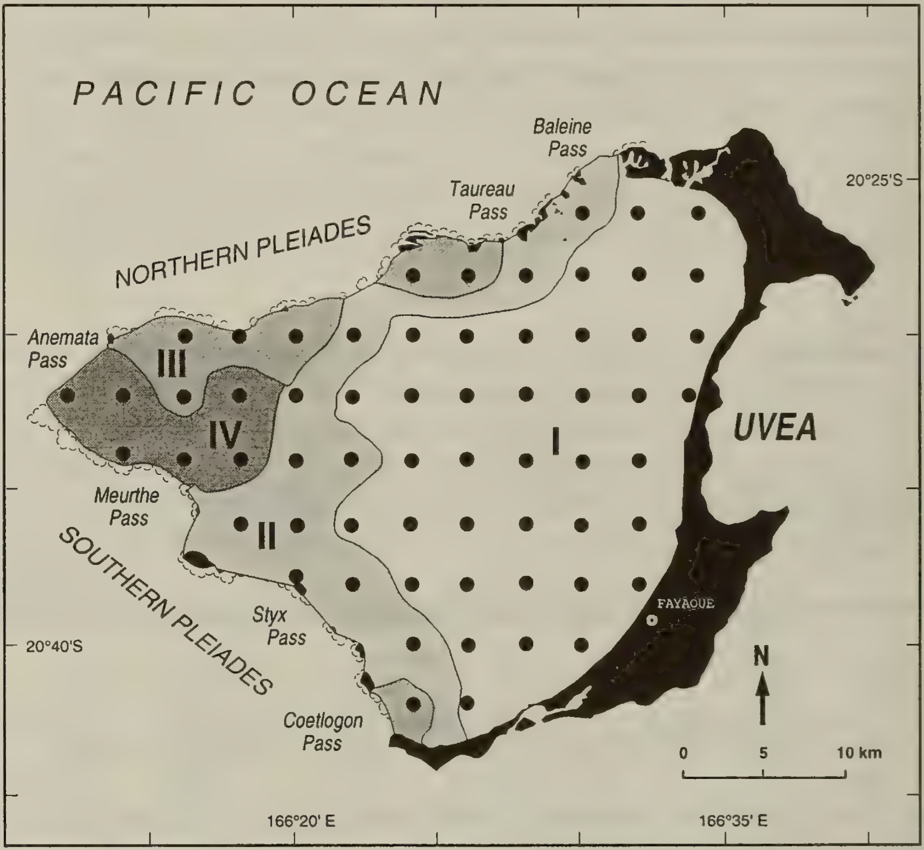


Figure 4. Location of the stations following tthe results of DECORANA analysis.

The means of biotic parameters in Group I are significantly greater than those of Group II, which are not significantly different from those calculated for Group IV characterised by a high percentage of hard ground cover. Group III has high mean values for ATP, chlorophyll *a* and organic matter. Because the organic matter content in sediment was measured from a 4 cm layer, its value is greatly dependent on the sediment thickness. This explains the low mean values for Groups II and IV. The distribution of the biomass by benthic community is heterogeneous (Table 4). Group I stations show the richest biomass. Algae are abundant (Fig.5) in particular *Halimeda melanesica* and *H. cylindracea.* The gastropod *Cerithium sp.* (cf. *tenuifilosum*) dominates animal biomass together with other gastropods such as *Vasum turbinellus* and *Rhinoclavis aspersa*, bivalves *Cardium enode* and *Arcopagia* (*Pinguitellina*) *robusta*, and the holothurian *Halodeima atra.* In Group II, plants only represent 25% of the total biomass, largely dominated by *Cyanophyceae* attached to hard substrate.

Table 4. Mean values of the environmental and biotic parameters for the four benthic communities defined using DECORANA (Surface in %; % mud = mud percentage; Mean grain size in mm; Sediment thickness in cm ; % hard bottom = hard bottom cover percentage; Depth in m ; ATP in ng/cm² ; Chlorophyll *a* and Phaeopigments in mg/m² ; Organic matter calculated on a maximum layer of sediment of 4 cm in g/m²; Macrobenthic biomass in g/m²; standard errors are in brackets).

	Group I	Group II	Group III	Group IV
Surface represented (%)	61	18	11	10
% mud	5.43	2.27	2.39	2.73
Mean grain size	0.38	3.97	0.40	1.40
Sediment thickness	4.34	2.31	24.79	2.92
% hard bottom	18.38	64.58	13.57	56.33
Depth	14.01	22.43	24.99	35.40
ATP	349.89 (23.05)	131.10 (42.40)	331.29 (71.77)	182.29 (54.21)
Chlorophyll *a*	93.33 (7.37)	42.99 (13.00)	58.37 (11.46)	47.12 (16.76)
Phaeopigments	42.74 (2.43)	19.42 (6.28)	23.58 (3.75)	26.67 (8.13)
Organic matter	1853 (117)	632 (196)	1795 (298)	982 (349)
Macrobenthic biomass	5.72 (1.63)	1.87 (0.33)	2.05	0.75 (0.04)

The animal community is similarly dominated by sessile species such as *Sarcophyton sp.* and sponges, together with the holothurian *Microthele nobilis* and the gastropod *Cerithium sp.* (cf. *tenuifilosum*). The biomass of Group III is almost entirely composed of macrofauna (Fig.5); algae are very scarce. Five species form more than 70% of the total biomass, i.e. the bivalves *Fimbria fimbriata* and *Trachycardium enode*, the gastropods *Rhinoclavis fasciata* and *Strombus gibberulus* and the fish *Callechelys sp.*. The biomass of Group IV is contributed to by sessile species such as the sponges *Pseudaxinissa cantharella* and *Spirastrella sp.*, and the cnidarian *Sarcophyton sp.*. Free living species are represented by the gastropods *Rhinoclavis fasciata, Cerithium sp.* (cf. *tenuifilosum*) and *Rhinoclavis articulata* distributed on hard substrates. Algae are almost absent. In terms of biomass, Group IV appears the poorest in the lagoon. Relative distribution of trophic-group biomass clearly differs among the four communities (Fig.6). Groups I, II and IV show a similar pattern of progressive decrease in the biomass of primary producers, carnivores and herbivores, and an opposite increase of suspension-feeder percentages. However, Group II is noteworthy for the relative proportions of the two deposit-feeder categories, surface deposit-feeders being abundant due to the holothurian *Microthele nobilis.* In comparison, Group III shows a different trophic structure, limited to three categories with a similar biomass : surface deposit-feeders, carnivores, and suspension-feeders and is intermediate between the Groups II and IV.

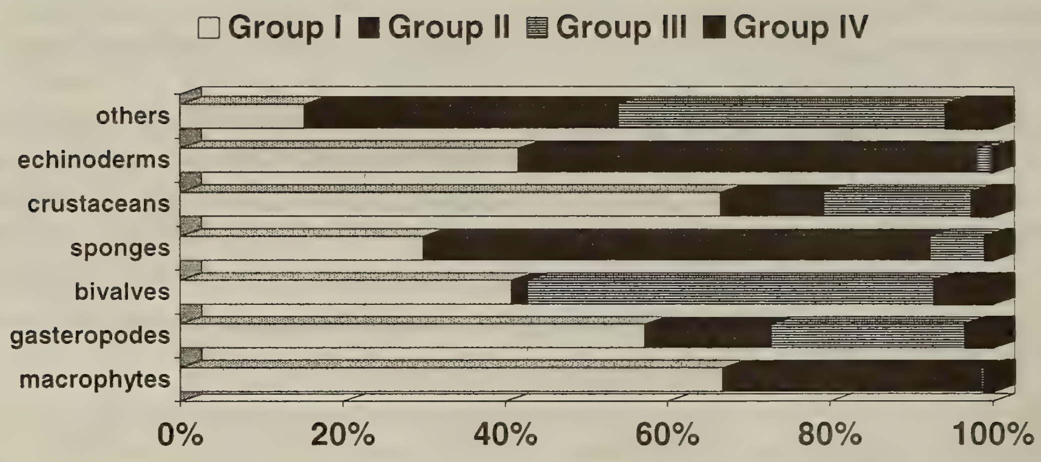


Figure 5. Biomass of the taxonomic groups for the benthic communities

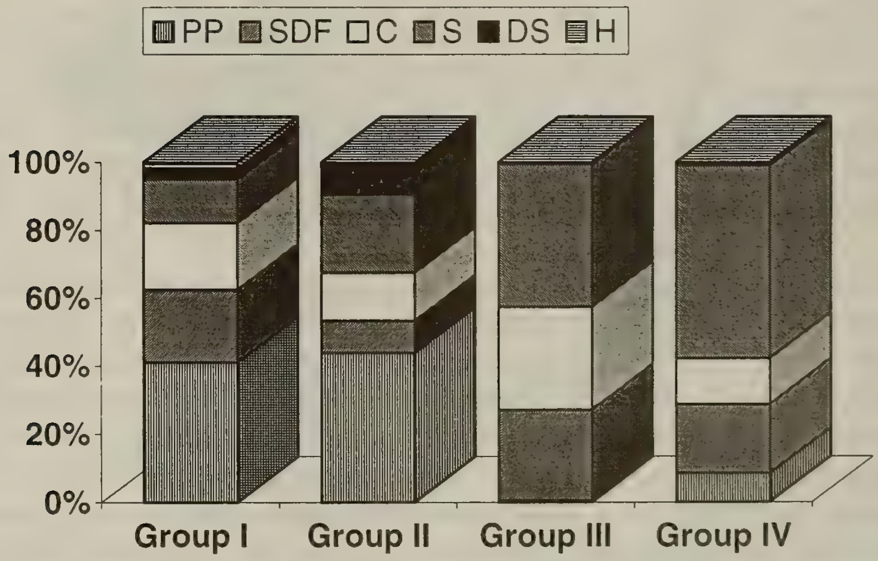


Figure 6. Biomass of the trophic groups for the benthic communities. (PP : primary producers ; DS : deposit-swallowers ; C : carnivores ; S : suspension-feeders ; SDF : surface deposit-feeders ; H : herbivores).

DISCUSSION

a. Micro and meiobenthos.

The mean ATP value in the Uvea Lagoon does not differ significantly from ATP values (294.1 ng/cm²) obtained for the same season and with similar methods by Garrigue et al. (1992) in the SW lagoon of New Caledonia (t test, P=0.95). However, our results are lower than Charpy-Roubaud's findings (1986) in Tikehau atoll (French

Polynesia) : 360 ng/cm², accepting a constant concentration over the top centimetre of sediment.

b. Microphytobenthos.

The mean values of chlorophyll *a* in Uvea Lagoon are significantly greater than the values found in the southwest lagoon of New Caledonia (47.16 mg/m²; Garrigue, 1995) and in the lagoon of Tikehau, French Polynesia (9.6 mg/m²; Charpy-Roubaud, 1988) (t test, $P=0.005$ and $P<0.001$, respectively). However, our findings are lower than the values found in Takapoto, French Polynesia (236 to 907 mg/m²; Sournia, 1976) for shallow foraminifera sands containing symbiontic algae. In contrast, the mean value of phaeopigments in Uvea Lagoon is significantly lower than that found in the southwest lagoon of New Caledonia (78.41 mg/m²) (t test, $P<0.001$). As a consequence of the high chlorophyll *a* content and the low phaeopigment content, there is a high percentage of chlorophyll *a* to total pigments (mean = 67.2%) in the lagoon of Uvea, this suggests a high microphytobenthic production. The importance of phaeopigment contents along Uvea island may be partly related to the disintigration of macroalgae that are found in great quantity at the coastal stations. The significant correlation between phaeopigment content, hard bottom cover and the sediment thickness indicate a preferential accumulation of seaweed detritus in areas of low sediment thickness. In this biotope, sand patches are located in substrate depressions or close to coral formations where organic debris concentrates. As there is no relation between organic matter content in the sediment and sediment thickness ($r=0.03$, $P=0.82$), we deduce that there is no accumulation of organic matter in these areas. Furthermore, ATP content and sediment thickness are significantly correlated. These facts suggest that organic matter is rapidly degraded by microbenthos and that areas with a thin sediment layer are the most important of the lagoon in terms of production.

c. Macrobenthos.

Using similar sampling methods, Chardy et al. (1987) identified 387 taxa from 35 stations in the SW lagoon of New Caledonia. This value is close to Uvea global richness. However, the number of taxa per sampling station (SW lagoon : 39.5 ; Uvea : 27.56) and the macrobenthic mean density (SW : 117 ind/m² ; Uvea : 59.66 ind/m²) were significantly greater in the SW lagoon (t tests, $P<0.00$ and $P=0.01$ respectively). Conversely, the mean diversity H' and the equitability E in Uvea Lagoon are slightly greater (Chardy et al., 1988). With 319 taxa, Uvea Lagoon has a high faunistic richness compared to that of Fiji's Great Astrolabe Lagoon (186 taxa; Clavier et al., 1996) and some Polynesian atolls such as Reao (less than 100 taxa ; Salvat, 1972), Tikehau (80 taxa ; Charpy and Charpy-Roubaud, 1994) or Mururoa (55 taxa ; Bablet et al., 1995). This richness could result from the biogeographic dispersion of species in the Pacific ocean decreasing from west to east (Eckman, 1953). In addition, Uvea Lagoon is of a greater size and due to numerous large passes (e.g. Anemata and Styx) is open to the oceanic circulation.

Hierarchy of the different zoological groups is fairly constant in Pacific soft bottom communities (Long and Poiner, 1994, Newell and Clavier, 1997, Baron et al., 1993), with a dominance of molluscs, followed by annelids and crustaceans. However, this composition is valid only for large macrofauna (>2mm), polychaetes being more abundant in 0.5-2 mm size class (Riddle, 1988, Newell and Clavier, 1997). The outstanding feature of Uvea Lagoon is the relative importance of gastropods species (Clavier et al., 1992).

The mean macrobenthic biomass in Uvea Lagoon is very similar to Fiji's Great Astrolabe Lagoon (4.70 gAFDW/m^2 ; Newell and Clavier, 1997) but almost six times smaller than that of the New Caledonia South West Lagoon (23.6 gAFDW/m^2 ; Chardy and Clavier, 1988). Conversely, macrobenthic biomass is higher than Central Pacific atolls : 0.009 to 2.04 gAFDW/m^2 in Mururoa Lagoon (Villiers, 1988) and 0.001 to 3.5 gAFDW/m^2 in Tikehau Lagoon (Bablet et al., 1995).

Taxonomic group biomass distributions, are the same in the three West Pacific lagoons. Of the macrofauna, molluscs dominate the biomass both in Tikehau, and in Uvea Lagoons whereas in Mururoa the polychaetes constitute the greatest part of the biomass with the molluscs representing just 10% of which only 2% are gastropods (Villiers, 1988). In Uvea the polychaetes are a minor group, and in Tikehau Lagoon they constitute only 9%. Two other minor zoological groups in Uvea, are important in Tikehau : the sipunculids (25%) and the sponges (27%) (Charpy and Charpy-Roubaud, 1994). The free-living cnidarian *Heteropsammia cochlea*, together with the commensal sipunculian *Aspidosiphon jukesi*, forms a major part of zoobenthic biomass in the SW lagoon of new Caledonia whereas they are seldom found in Uvea Lagoon.

The importance of the macrophytic primary producers is highlighted in the trophic structure of the Uvea Lagoon. Comprising roughly 40% of the overall macrobenthic biomass, they dominate the system. The same pattern has been found in Fiji's Great Astrolabe Lagoon and in the SW Lagoon of New Caledonia (Chardy and Clavier, 1988 ; Garrigue, 1995 ; Newell and Clavier, 1997). In the Central Pacific, the macrophytes represent a greater proportion of the total biomass in Tikehau lagoon (60 %). The primary produce group could be enlarged by adding the other categories of photosynthetic organisms : microphytobenthos, phytoplankton, endolithic algae and symbiotic algae. Endolithic algae, symbiotic algae and phytoplankton were not studied in the present work, however microphytobenthos were measured using benthic chlorophyll *a*.

To evaluate the relative importance of microphytobenthos to macrophytobenthos we have expressed the results in carbon, assuming that carbon represents 40% of the ash-free dry weight biomass (Steele, 1974) and that the ratio of carbon / chlorophyll *a* = 50 (Charpy and Charpy-Roubaud, 1990). From this evaluation, the biomass of microphytobenthos (3.85 gC/m^2) is six times greater than the biomass of macrophytobenthos (0.62 gC/m^2) in the Uvea Lagoon, whereas it represents only half of the macrophytobenthos (micro : 2.4 gC/m^2 and macro : 5.2 gC/m^2) in the SW Lagoon of New Caledonia (Garrigue, 1995). This is partly due to the scarcity of macrophytes in Uvea Lagoon but more specifically to the importance of the microphytobenthos on the bottom of Uvea Lagoon. The significance of microphytobenthos explains the importance of the surface deposit-feeders biomass, especially that of the gastropod *Cerithium sp.* (cf. *tenuifilosum*) that dominates this group. This species preferentially lives in areas with low sediment thickness and feeds on a microphytobenthic film that covers the substrate surface. Compared to the other trophic groups, the carnivores seem to be abundant, but their biomass represents only two-thirds of that measured in the SW Lagoon, where this group was considered to be of minor importance. The overabundance of necrophagous species compared to other benthic fauna suggests an exogenous input of organic matter such as decayed fishes from the lagoon.

The high occurrence of *Cyanophyceae* noticed during most of the investigations carried out on the lagoons (Chevalier et al., 1968 ; Colin, 1987 ; Intes and Caillart, 1994), suggests that microphytobenthos is a characteristic of the lagoons of the atoll. For example, one of the four communities has been described in Enewetak Lagoon as ''sand substrate with visible algal mat''. This mat can reach 1 m in diameter (Colin, 1987). At the same time, the great abundance of *Cerithidae* in the lagoon of Mururoa (Salvat and Renaud-Mornant, 1969), *Strombus luhuanus* in Enewetak (Colin, 1987) and the dominance of deposit-feeders in Tikehau lagoon (46% of biomass ; Charpy and Charpy-Roubaud, 1994) could suggest the importance of the role played by deposit-feeders.

CONCLUSIONS

Due to its situation on the slope of the lithospheric bulge Uvea Atoll presents a depth gradient that increases regularly from Uvea Island in the east to Anemata Pass on the west, and a thin layer of sediment associated with a high proportion of hard substrate. The decrease in the sediment thickness is probably a result of hydrodynamic turbulence coming from large passes that open widely to the surrounding ocean. These two phenomena could explain most of the observed structures. The spatial distributions of organisms were different than those observed in a typical atoll, the center of which constitute a sink where organisms are scarce. In Uvea, the main part of the benthos is found in the shallow waters close to the island. The deterioration of benthic communities follows a decrease of sediment thickness and an increase in depth. Our approach allows us to describe four main benthic communities in the Uvea Lagoon. Such a classification is essentially a convenient model of a more complex situation. In fact, sampling stations are distributed along gradients and their allocation to one group or another is sometimes uncertain.

Uvea Island and its lagoon exhibit the geomorphological characteristics of an atoll. From a sedimentological point of view, the sediment is exclusively carbonates with a low mud content (Chevillon et al., 1992 ; Chevillon, 1996). Biologically, numerous features allow the distinction between the lagoon of an atoll and a coastal lagoon that is under the influence of terrigenous inputs. Compared to the coastal SW Lagoon of New Caledonia, the macrobenthos of the Uvea Lagoon is both low in abundance and biomass, but the high percentage of active chlorophyll *a* suggests a high microphytobenthic production, which enters into the trophic system directly or indirectly via bacteriological transformation. It represents an important source of food for the deposit-feeders which could explain the preponderance of this trophic group in the trophic structure of the lagoon.

From a biogeographic point of view, this study demonstrates the richness of the lagoon of Uvea Atoll, in terms of benthic species and biomass, compared to other central Pacific atoll lagoons. For Uvea Lagoon itself, these results highlight the existence of an east to west gradient between Uvea Island and Anemata Pass.

ACKNOWLEDGEMENTS

Uvea Atoll is part of the Province Iles. This study was carried out under an agreement between ORSTOM, the State and Province Iles, as part of a multidisciplinary program on fish resources of the lagoon of Uvea. We thank the crew of *R.V. Alis*, the divers and the technicians for their help at sea.

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ATOLL RESEARCH BULLETIN

NO. 453

THE REPTILES OF KAPINGAMARANGI ATOLL, MICRONESIA

BY

DONALD W. BUDEN

ISSUED BY
NATIONAL MUSEUM OF NATURAL HISTORY
SMITHSONIAN INSTITUTION
WASHINGTON, D.C., U.S.A.
SEPTEMBER 1998

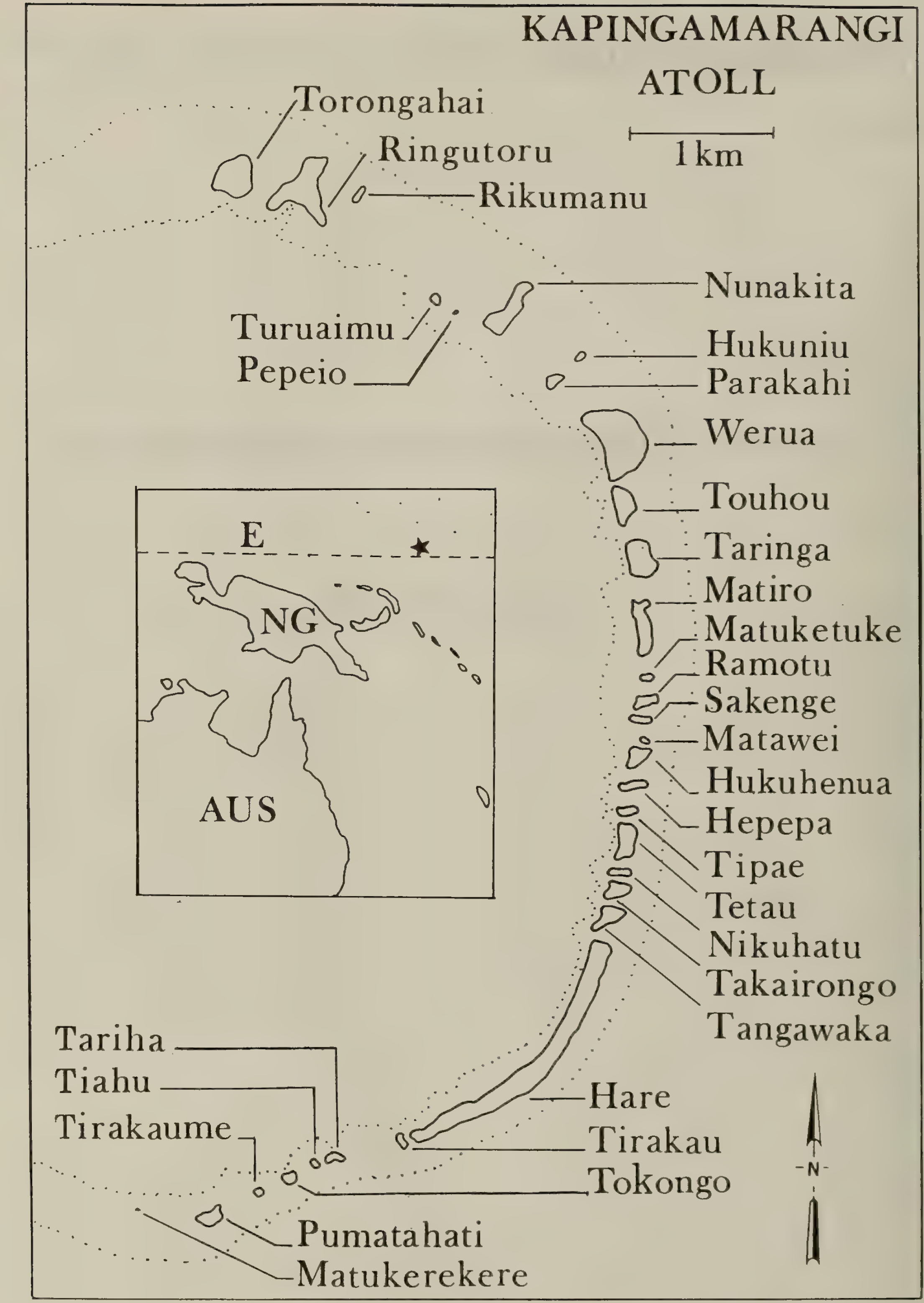

Figure 1. Location map for Kapingamarangi Atoll. AUS =Australia, NG = New Guinea, E = equator, star = Kapingamarangi.

THE REPTILES OF KAPINGAMARANGI ATOLL, MICRONESIA

BY

DONALD W. BUDEN[1]

ABSTRACT

Two species of sea turtles and eight lizards comprise the herpetofauna of Kapingamarangi Atoll; the giant Micronesian gecko (*Perochirus scutellatus*) is unknown elsewhere. The mourning gecko (*Lepidodactylus lugubris*), oceanic gecko (*Gehyra oceanica*), and azure-tailed copper-striped skink (*Emoia impar*) are the most common and widespread species, being recorded on 100%, 97%, and 87% of the 31 islands, respectively. The stump-toed gecko (*Gehyra mutilata*) and the Pacific blue-tailed skink (*Emoia caeruleocauda*), both known from only a scattering of older records from the most densely inhabited and most frequently visited islands, may be extirpated or possibly still exist locally in very small numbers. Sea turtles are rare and none was observed during the present study, but local residents indicate they were more numerous in the past.

INTRODUCTION

The herpetofauna of Kapingamarangi has not been previously surveyed systematically. Six *Emoia impar* collected by H. K. Townes in 1946 are in the National Museum of Natural History, Smithsonian Institution (USNM). Niering (1963) remarked briefly on seven species of reptiles encountered during a joint Pacific Science Board, National Academy of Science/Office of Naval Research Expedition during 22 June-31August 1954; 83 specimens were deposited in USNM collections. At approximately the same time, the George Vanderbilt Foundation Expedition collected lizards for the California Academy of Sciences (CAS and CAS-SU) adjunct to field surveys of Pacific fishes. The interaction and degree of overlap in activities between the two expeditions on Kapingamarangi is uncertain. Robert R. Harry, the principle collector of lizards for the Vanderbilt group was acknowledged by McKee (1956) as contributing geological information for Niering's group, but he was not mentioned in any of the natural history reports presented by Niering (1956, 1963) and Wiens (1956).

One specimen each of *G. mutilata* and *G. oceanica* collected at Kapingamarangi by W. Mierina in July 1974 also are in CAS collections, and Ota et al. (1995) remarked on variation in *Lepidodactylus lugubris* collected there. Brown (1976) discussed taxonomic relationships of *Perochirus scutellatus*, which is known only from Kapingamarangi, and at

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Manuscript received 8 April 1998; revised 9 June 1998

that time only from two specimens—the holotype in the British Museum of Natural History (BMNH) and a nontype in CAS. The present study is based largely on my observations and specimens collected during 19 June-13August 1996, along with information extracted from the literature and museum collections.

STUDY AREA

Kapingamarangi Atoll is a Polynesian outlier in southeastern Micronesia at 1° 04' N, 154° 05' E. It is about 11.2 km long (east to west) and 8-9 km wide, and with a land area of about 1.3 km^2 distributed among 31 low-lying, coralline islands, all at the eastern end (Fig.1). The vegetation is mainly *Cocos* (coconut) or mixed *Cocos/Artocarpus* (breadfruit) forest with a narrow and discontinuous band of coastal scrub or thicket consisting largely of *Scaevola* and *Tournefortia* shrubs. The approximately 500 islanders nearly all live on Werua and Touhou, but they utilize the other islands for cultivation (mainly *Cyrtosperma* taro) and for harvesting other plant materials for food, fuel, handicrafts, and housing construction. The vegetation has been modified over a long period of human occupation (Niering 1956, 1963; Wiens 1956).

METHODS

All 31 islands were visited both at night and in daylight, and an effort was made to obtain at least one voucher specimen of every species encountered on every island. Specimens were collected by hand, and the number collected in each habitat does not necessarily give a completely accurate measure of habitat preference as values may be skewed by differences in ease of capture. A disproportionately large number of *Emoia impar*, for example, was collected on tree trunks as the lizards were more readily captured there than on the forest floor, where they were more numerous but much more elusive. More accurate estimates of abundance were obtained during census counts recording all individuals observed.

Daytime surveys included counts made during slow walks along measured transects, timed searches of more cryptic habitats (in leaf litter, in palm leaf axils, beneath loose bark), and opportunistic observations and collections throughout the study period. Nighttime surveys were conducted at different times between dusk and dawn and consisted largely of timed observations in different habitats using a hand-held light. Distances were estimated from an aerial photomosaic map (Pohnpei State Land Commission 1986) and place names are from Bryan (1971). The specimens were deposited in the Australian Museum (Sydney), Bernice P. Bishop Museum (Honolulu), British Museum of Natural History (London), California Academy of Sciences (San Francisco), College of Micronesia (Pohnpei), Museum of Comparative Zoology, Harvard University (Cambridge, Massachusetts), and National Museum of Natural History Smithsonian Institution (Washington, D.C.).

SPECIES ACCOUNTS

***Chelonia mydas* and *Eretmochelys imbricata*.**—The scanty records and the anecdotes of resident islanders suggest that turtles never were very abundant on Kapingamarangi, at least in historical times. Local residents told me that both green turtles (*C. mydas*) and hawksbill turtles (*E. imbricata*) are seen occasionally, but were more numerous in the past. I saw no turtles during summer 1996. In the mid-1980s, a resident told Herring (1986) that "hawksbill turtles nest on the lagoon side of Ruguero [= Ringutoru]," and that they formerly nested on the southern end of Hare, but "too many island residents caused the turtles to discontinue nesting"; he was uncertain as to the breeding status of green turtles. Niering (1963) observed a green turtle "about 3 ft in length" that had been caught by local fishermen in summer 1954. Emory (1965), having visited Kapingamarangi in 1947 and 1950, stated "turtles…are quite rare and it is forbidden to kill them," and turtle bones were a "rarity" in the only archaeological excavations on the atoll (Leach and Ward 1981).

***Gehyra mutilata*.**—Niering (1963) considered the stump-toed gecko rare "around the village," and he collected one (USNM 139799) on Werua on 25 August 1954. Another specimen (CAS 139712) was collected on Touhou by W. Mierina on 24 July 1974. These are the only records; I saw none during two months on the atoll. Possibly the few previous records represent a recent introduction that has since been extirpated or possibly continues to exist locally in extremely small numbers.

***Gehyra oceanica*.**—Niering (1963) "frequently" encountered the oceanic gecko on *Cocos* trunks and collected it also "under debris and in the villages." One specimen obtained by R. R. Harry either on Touhou or Werua in August 1954 and another collected by W. Mierna on Werua in July 1974 are in CAS collections. I observed *G. oceanica* on all the islands with the exception of Matukerekere (Table 1). Most of the 94 specimens I collected were in young palm leaf axils (28.8%, mainly juveniles) during the day and on tree trunks at night (24.5%, mainly adults). Both adults and juveniles were often encountered on shrubs and bushes at night, especially in *Scaevola* at the forest edge (Table 2).

***Lepidodactylus lugubris*.**—The mourning gecko is widespread and generally common throughout Kapingamarangi. It is the only lizard recorded on all 31 islands, including diminutive Matukerekere where I collected two in the leaf axils of young *Cocos* trees. It occurs abundantly in edificarian sites as well as in all native and ornamental vegetation types. I observed it most frequently at night in coastal scrub and strand, especially on the outer edges of *Scaevola* and *Tournefortia* bushes along the upper beach zone. Ota et al. (1995) reported one hybrid *L. lugubris* x *L. moestus* among 11 *Lepidodactylus* collected by R. R. Harry in 1954, and they speculated on the likelihood of true *L. moestus* being there. But all 131 specimens of *Lepidodactylus* I collected (most of which were examined also by R. Fisher) are *L. lugubris*.

Table 1.—Distribution of lizards on Kapingamarangi Atoll, with numbers of specimens collected during summer 1996; SR = sight record only, this study.

	Species[a]							
Island	G.m.	G.o.	L.l.	P.a.	P.s.	E.c.	E.i.	L.n.
Torongahai		2	1		28		2	2
Ringuturo		4	6				2	2
Rikumanu		1	1				2	
Turuaimu		2	1	10	1			
Pepeio		SR	1		6			
Nunakita		2	4	23	2		2	1
Hukuniu		1	2		13		1	
Parakahi		1	2	10	16		2	
Werua	+[b]	12	9	+[c]		+[d]	13	2
Touhou		4	6	1[e]			1	
Taringa		8	2	1	4		2	1
Matiro		6	3	12	45		1	3
Matuketuke		1	11				1	
Ramotu		3	4				2	1
Sakenge		3	3		4		1	
Matawei		3	4		1			
Hukuhenua		5	1		SR		1	2
Hepepa		1	1				1	
Tipae		1	3		2		1	
Tetau		1	3		3		3	SR
Nikuhatu		1	9		1		1	1
Takairongo		1	1		12		2	
Tangawaka		4	5		5		3	1
Hare		19	25		2		6	14
Tirakau		2	6		1		1	
Tariha		1	2				1	
Tiahu		1	1				1	
Tokongo		2	3				1	
Tirakaume		1	2				2	
Pumatahati		1	7				2	
Matukerekere			2					

[a] G. m. = *Gehyra mutilata*, G. o. = *Gehyra oceanica*, L. l. = *Lepidodactylus lugubris*, P. a. = *Perochirus ateles*, P. s. = *Perochirus scutellatus*, E. c. = *Emoia caeruleocauda*, E. i. = *Emoia impar*, L. n. = *Lipinia noctua*.

[b] Recorded in 1954 and 1974 (see text), but not observed during summer 1996.

[c] Fifteen specimens collected in summer 1954 are the only records.

[d] One specimen collected in 1954 is the only record.

[e] One specimen collected in 1954 and another during 1996 (in coconuts apparently brought in from another island) are the only records.

Perochirus ateles.—The Micronesian gecko is less common than its much larger congener *P. scutellatus*, being found on only seven of 31 islands, all in the northern half of the chain to as far south as Matiro. R. R. Harry collected 15 on Werua and one on Touhou, and Niering collected one each on Torongahai and Ringutoru. I saw none on Werua and the only one I saw on Touhou was in a cut bunch of coconuts probably brought in from another island. Of the 56 specimens I collected, 37 (66%) were in palm leaf axils and the others were roughly evenly distributed among shrubs and bushes at night and under loose, flaking bark on standing trees during the day (Table 2); none was seen exposed in daylight. *P. ateles* occurs syntopically with *P. scutellatus*; both were collected together on the same shrubs, tree trunks, and palm leaf axils. How *P. ateles* and juvenile *P. scutellatus* partition food resources is uncertain, though adults doubtless utilize differently sized food items as snout-vent length among the largest *P. ateles* averages about 70 mm (based on measurements of only four specimens, but observations of many others), whereas adult male *P. scutellatus* average 116.5 mm and females 98.4 mm (Buden 1998), and *P. ateles* is nocturnal, whereas *P. scutellatus* is predominately diurnal.

Perochirus scutellatus.—The giant Micronesian gecko is known only from Kapingamarangi Atoll. I observed it on 18 of 31 islands, and with encounter rates as high as 150 per hour and 25 per tree. It is primarily diurnal and arboreal with a predilection for *Guettarda* trunks. It is the largest lizard on the atoll; adult males weigh as much as 60 g and measure up to 132 mm in snout-vent length, and males average nearly twice the body mass of females. These and other facets of morphology and ecology are discussed at greater length elsewhere (Buden 1998).

Emoia caeruleocauda.—The only record of the Pacific blue-tailed skink is one specimen (CAS-SU 25633) collected on Touhou by the George Vanderbilt Foundation Expedition on 1 August 1954. It may have been a recent introduction possibly in cargo from Pohnpei. There is no corroborating evidence to suggest a viable population now or formerly.

Emoia impar.—Niering (1963) recorded *Emoia impar* under *E. cyanura* and considered it "the most abundant vertebrate" on the atoll. The 59 azure-tailed copper-striped skinks collected on Touhou and Werua islands by R. R. Harry on 23 July 1954 are CAS-SU 25639-25697; 59 others collected on Ringutoru and Werua by Niering during June-August 1954 are USNM 139823-139875, and the six collected by H. K. Townes on Hare on 3 August 1946 are USNM 123912-123917. I recorded *E. impar* on 27 of the 31 islands and with encounter rates averaging 75/km and 84/hr, and ranging from 5-15/hr on the smaller islands to as high as 289/hr on Ringutoru and 222/hr on Hare. The only islands where I did not see *E. impar* are Turuaimu, Pepeio, Matawei, and Matukerekere, all being less than 1 hectare in area and among the smallest islands on the atoll. This species is most numerous in patches of sunlight on the forest floor, less common on tree trunks (occurring mainly 1-2 m high on breadfruit trees), and occasionally low on ground cover and understory plants. The number of specimens collected on trees is disproportionate to occurrence as lizards were more easily captured on tree trunks than on the ground.

Table 2.—Habitat distribution (percent frequency) of lizards collected on Kapingamarangi Atoll during summer 1996; D = daytime, N = night.

	Species[a]					
Habitat	G.o.	L.i.	P.a.	P.s.	E.i.	L.n.
Tree trunks (D/N)	24.5	0.8		73.6	31.0	32.3
Under loose bark (D)	9.6	9.2	16.1	0.7	1.7	32.3
Inside logs and stumps (D)	2.1	0.8				3.2
Palm-leaf axils (D)	28.8	11.5	66.1	11.8		12.9
Shrubs and bushes (N)	20.2	74.8	17.9	13.9		
Taro pits (N)	8.5	1.5				
Forest floor (D)					63.8	12.9
Grassy areas (D)					3.5	
Edificarian sites (D/N)	6.4	1.5				6.5
Total specimens collected	94	131	56	136	58	31

[a] G.o. = *Gehyra oceanica*, L.i. = *Lepidodactylus lugubris*, P.a. = *Perochirus ateles*, P.s. = *Perochirus scutellatus*, E.i. = *Emoia impar*, L.n. = *Lipinia noctua*.

Table 3.—Encounter rates (individuals per hour) of lizards in three habitats on Kapingamarangi Atoll during summer 1996.

	Habitat and survey time		
Species	Palm-leaf axils[a] 8.9 h	*Scaevola* shrubs[b] 6.7 h	Forest floor[a,c] 6.8 h
Gehyra oceanica	16.1	1.2	0
Lepidodactylus lugubris	1.6	10.5	0
Perochirus ateles	5.2	0.6	0
Perochirus scutellatus	2.6	3.1	0
Emoia impar	0	0	84.2
Lipinia noctua	0.9	0	0

[a] Surveyed in daylight.

[b] Surveyed at night.

[c] Including ground cover.

Lipinia noctua.—Niering (1963) recorded only two examples of the moth skink on Kapingamarangi during summer 1954—"one specimen was collected on a small coconut and the other in a native house," both at unspecified sites, but they are almost certainly USNM 139876 from Hare and 139877 from Werua. I found *L. noctua* widespread on 12 different islands between Torongahai and Hare, but none on the seven southernmost islands (Table 1). With the exception of one in leaf litter at dusk, all of my sightings were in daylight (0750-1730), about 45% were exposed on tree trunks (mainly *Artocarpus*) and on the forest floor, the remainder being under loose bark, in palm leaf axils, or under manmade objects (Table 2). The pale yellow nuchal spot, very conspicuous in the field, accounted for many initial sightings at distances of 5-10 m.

DISCUSSION

Eight species of lizards (5 geckos, 3 skinks) and two species of sea turtles are known from Kapingamarangi Atoll. *Gehyra oceanica*, *Lepidodactylus lugubris*, and *Emoia impar* rank highest in incidence, being recorded on at least 27 (87%) of the 31 islands, and usually being common to very common wherever they occur. *L. lugubris* is the only species recorded on all the islands, and *G. oceanica* is absent only on Matukerekere, the most remote and diminutive island. *G. mutilata* was observed in 1954 and 1974, and *Emoia caeruleocauda* is known from only one specimen collected in 1954. The records for both species are confined to the Touhou-Werua area and possibly represent relatively recent introductions that had not spread beyond the colonization site and have since been extirpated, or possibly they continue to exist in very small numbers (none was seen during June-August 1996). Excluding both *G. mutilata* and *E. caeruleocauda*, *Perochirus ateles* has the most restricted distribution among lizards on Kapingamarangi, being found on only six islands, and all between Turuaimu and Matiro in the northern part of the chain. Competition does not appear to be a limiting factor in this case as *P. ateles* occurs syntopically with all three other gecko species on five of the six islands—*P. scutellatus* being absent on Touhou, where *P. ateles* is rare if it still occurs.

All six lizard species observed during summer 1996 occurred in *Cocos* forest, but only *Lepidodactylus lugubris* and *Gehyra oceanica* also were seen frequently on buildings and other man-made structures. The two skinks (*Emoia impar*, *Lipinia noctua*) also occurred in edificarian habitats but were relatively more numerous outside the settlements and in the forest—*E. impar* being largely on the forest floor and *L. noctua* mainly beneath loose bark, and less frequently, on tree trunks.

Perochirus scutellatus is a large, predominately diurnal and presumably insectivorous tree trunk species that appears to occupy a niche utilized by the green tree skink (*Lamprolepis smaragdina*) on other Pohnpei State atolls I have studied, including Pohnpei and its lagoon islands, as well as Ant, Pakin, Mokil, and Pingelap atolls. *P. scutellatus* is known only from Kapingamarangi Atoll. In view of its limited geographic range, despite relatively high population density on some islands, this species should be considered rare and endangered or threatened, and its status should be factored into assessments of any projects that would modify habitat on islands where it occurs. *P. scutellatus* does not appear to be adversely affected by traditional agroforestry and small-scale cultivation, but its absence or scarcity in edificarian habitats and in the vicinity of human habitation suggests it is sensitive and vulnerable to habitat change.

ACKNOWEDGMENTS

I thank Jens Vindum for information on specimens in the California Academy of Sciences, and Ron Crombie and George Zug for information on Kapingamarangi specimens in the USNM (Smithsonian Institution) collections, and for reviewing the manuscript. Field work was supported by a grant from Pacific Island Network (PIN) and I thank Ahser Edward (Sea Grant, Pohnpei) and Sharon Ziegler (Sea Grant, Honolulu) for assistance in obtaining this funding. I am also grateful to the people of Kapingamarangi who assisted me directly in many different ways and granted me permission to travel freely among their islands.

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ATOLL RESEARCH BULLETIN

NO. 454

POPULATION STATUS OF PTEROPUS TONGANUS IN TONGA

BY

GILBERT S. GRANT

ISSUED BY
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SMITHSONIAN INSTITUTION
WASHINGTON, D.C., U.S.A.
SEPTEMBER 1998

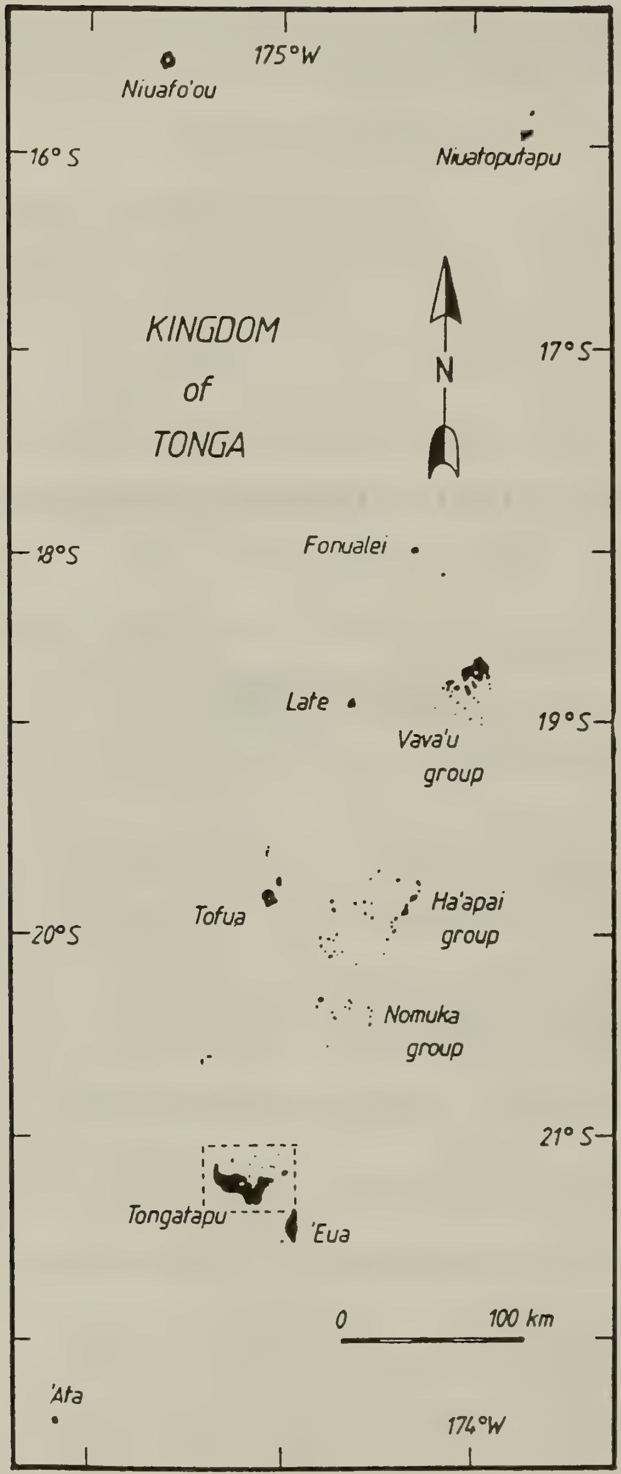

Figure 1. Map illustrating the major islands and island groups in the Kingdom of Tonga.

POPULATION STATUS OF PTEROPUS TONGANUS IN TONGA

BY

GILBERT S. GRANT[1,2]

ABSTRACT

Flying foxes (Pteropus spp.) are important pollinators and seed dispersers in many island ecosystems. Populations of flying foxes have declined markedly on most islands in the South Pacific since the 1940's. One potential conservation strategy is to reintroduce bats on islands where they historically occurred. In this manner, the risk of species extinction due to local catastrophic events can be reduced. Ideally the source population for such reintroductions must be robust. One such population might be in the Kingdom of Tonga, where flying foxes have been protected by local custom for a long time. However, virtually nothing has been published on the numbers, locations, and reproductive biology of Pteropus tonganus in Tonga. I therefore censused flying fox populations on as many islands as possible from 28 June to 26 July 1995. I found seven major roosts containing a total of 3,582 bats on Tongatapu, one roost with 30 bats in the Ha'apai group, and 27 roosts with a total of 5,925 bats on 14 islands within the Vava'u group. Thus, the flying fox population in Tonga seems robust and dispersed on many islands and is therefore a valuable potential source population.

INTRODUCTION

In addition to the cultural significance of flying foxes to the Polynesian people, these bats play an important role as pollinators of flowers and in dispersing seeds of native rainforest trees (Cox et al., 1992; Banack, 1995). In the Old World tropical forests, at least 289 plant species rely on large populations of flying foxes for pollination and seed dispersal. These plants produce some 448 economically valuable products for humans (Fujita and Tuttle, 1991). Island floras have a high degree of endemism and flying foxes have been hypothesized to be strong interactors on South Pacific islands where they serve as the principal pollinators and seed dispersers. The extinction of flying fox populations on Pacific islands may ultimately lead to plant extinctions (Cox et al., 1991).

On many islands in Micronesia, Melanesia, and Polynesia, flying foxes are still hunted for food (Graham, 1992 and references therein) primarily at the subsistence level.

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Manuscript received 14 October 1997; revised 29 January 1998

However, in some areas of Micronesia bats are harvested commercially (Stinson et al., 1992).

On Tonga, flying foxes (Pteropus tonganus) are considered the property of the King and can only be harvested by royalty. Consequently, the bat population is protected from human exploitation. This is in marked contrast to declining flying fox populations elsewhere in Polynesia and Micronesia (Graham, 1992). Despite the presence of an easily accessible roost which has become a tourist attraction in the village of Kolovai on Tongatapu, Kingdom of Tonga, little information about the numbers of bats present and their behavior has been published.

Local flying fox populations are vulnerable to hurricanes, overhunting, habitat loss, and deforestation (Craig et al., 1994; Miller and Wilson, 1997). Should a P. tonganus population become extinct on Niue or American Samoa, for example, the apparently healthy population on Tonga might serve as a source for reintroductions. Maintaining viable populations on many islands may be an effective conservation strategy for small populations of flying foxes on oceanic islands. Repopulating islands that historically supported bat populations reduces the risk of species extinction due to a single catastrophic event.

Ideally, the source population must be robust. I located roosts and censused flying foxes on 16 of the 171 total islands (697 km^2) in Tonga (see Fig.1) from 28 June to 26 July 1995. Only about 36 of these islands are inhabited by humans.

MATERIALS AND METHODS

I located daytime roosts on Tongatapu (28 June-18 July 1995) by driving or walking all roads and trails, observing evening dispersal flights of bats, and conversations with locals. In the Ha'apai group (18-20 July 1995), I travelled the backroads on Lifuka and Foa Islands and also positioned myself in the evening at the north end of Foa Island so that I might witness interisland movements between Foa and Nukunamo Island. In the Vava'u group (20-26 July 1995) I hiked up to the summit of Mt. Talau, searched for roosts on the main island of Uta Vava'u, and travelled by boat to offshore islands.

I recorded the locations of daytime roosts on maps, counted the numbers of bats, identified the tree species used by bats, and determined the reproductive status (attached babies, mating vocalizations) where possible. At roost sites I used direct counting of all bats seen as my estimate of the number present. This technique underestimates the total number of bats present because in trees with dense foilage (Mangifera indica and Ficus spp.) many non-flying bats are not detected. Most of the roosts at coastal sites were located on ridges or slopes. I measured the compass orientation of these roosts where possible to determine if sites chosen by the bats offered thermal and/or convective advantages or disadvantages.

RESULTS

I found seven major roosts (Figs. 2 and 3) totalling 3,582 P. tonganus on the island of Tongatapu (Fig.4; Table 1). The largest roost was along either side of the main road in the adjacent villages of Kolovai and Ha'avakatolo. I counted 1,355 bats in 28 trees (Table 1) at this roost. In the Ha'apai group, I saw a few bats on Lifuka and Foa Islands and saw one bat fly from Nukunamo Island to Foa at dusk on 19 July. I found one small roost of 30 bats on Lifuka Island. In the Vava'u group, I counted 5,925 bats in 27 roosts located on 14 islands (Table 1).

All roosts on the low-lying island of Tongatapu were inland. The single roost on the low-lying Lifuka Island was also inland. However, most roost sites on the elevated islands in the Vava'u group were coastal and most faced the west (277° ± 35 SD, n = 26) (Fig. 5, Table 1).

I determined the tree species utilized for day roosts by 3,492 P. tonganus at several roosts, primarily on Tongatapu and Lifuka. Most (87.6 %) of the bats roosted in Casuarina sp., Mangifera indica, and Eucalyptus sp. (Table 2).

I observed interisland movements of flying foxes in all three island groups. Four bats flew over the village of Kolonga on Tongatapu towards 'Eue'iki (6 km) on 10 July 1995 (Fig. 4). Fifteen bats flew over Ha'atala and the Christianity Landing Point on the west end of Tongatapu towards the offshore islet of 'Atata (8 km) on 11 July 1995. Two or three bats arrived at dusk on Fafa' Island (6 km) from Tongatapu on 27 July 1995. In Ha'apai, I witnessed one bat fly from Nukunamo Island to Foa Island (0.5 km) on 19 July 1995. In the Vava'u group (Fig. 5), at dusk on 22 July 1995 I saw bats flying between Oto, Luakapa and Kapa Islands (1-2 km).

I saw harems, babies, and copulations in 5 of 7 roosts on Tongatapu (Pea, Kolovai, Fatai, Ha'ateiho, and Tofoa) and in 5 of 26 roosts in the Vava'u group (Ofu, Mafana, Makave #2, Tauta, A'a #2). However, the observation distance and unstable boat platform in Vava'u made it difficult to detect evidence of breeding in most of these roosts.

I heard bats on Tongatapu at night while they were feeding in a Hernandia sonora tree. On Fafa' Island, off Tongatapu, I watched one bat lick nectar from flowers of three coconut palms (Cocos nucifera) at dusk on 27 July 1995. On Lifuka Island in the Ha'apai group I heard bats squabbling at night in a Terminalia catappa tree and 30 - 40 partially chewed fruit were seen on the ground the next morning. Five of these clearly had bat claw and tooth marks. On Vava'u, I heard bats at night in Ceiba pentandra trees that were in flower at the time.

DISCUSSION

The population of flying foxes in Tonga seems robust. A minimum of 9,500 Pteropus tonganus were counted in known roosts, and roost counts in most instances were probably an underestimate of the total number of bats in the roosts. Invariably, many additional bats were not detected due to the dense foilage in some roost trees, particularly mangos (Mangifera indica). In my experience, evening dispersal counts from roosts frequently revealed additional bats. On many occasions roost exit counts on American Samoa were twice as high as daytime counts. On Tongatapu, an evening dispersal count at Kolovai (1,413 bats) was similar to the daytime count (1,355 bats). However, I could see only a portion of exiting bats and my field of view narrowed considerably as total darkness approached. More than 2,000 bats were probably using the Kolovai-Ha'avakatolo roost.

Additional colonies of bats were reported on other islands within the Ha'apai group by locals and crews of sailing vessels. Reported roosts on Hunga, Fofoa, and Umuna Islands in the Vava'u group could not be verified due to time constraints and inclement weather. Some steep cliff-side colonies also probably exist on the west side of the main island of Uta Vava'u and on the wooded islands of Fonua'one'one, Luaafuleheu, Luahiapo, Lua ui vaha, Fua'amotu, and Fatumanga in southern Vava'u group. Gill (1987) reported seeing roosting bats in trees on 'Eua Island and Rinke (1987) observed bats on Kalau Island (south of 'Eua Island). Rinke et al. (1992) found a large colony on the northwest forested slope and a smaller one in the south on the island of 'Eue'iki (6 km offshore of Tongatapu Island). Rinke (1991) reported flying foxes on Late Island and found colonies on all of the small islands in the crater lake of Niuafo'ou Island. Thus, the flying fox population in Tonga is sizeable and is distributed on many islands from 'Eua and Kalau in the south to Niuafo'ou in the far north.

I feel confident that I found all of the significant colonies on the island of Tongatapu. Interestingly, several natives remarked that the bat roosts on Tongatapu have spread eastward from Kolovai to the remainder of the island during the last twenty years. Although a roost was reputed to be in a cocoa (Theobroma cacao) plantantion near Fatumu on the east side of Tongatapu, I could find no bats there. One resident reported that the farmers had chased the bats away to minimize damage to crops in the area. According to residents, the roost in Tofoa was much larger in the recent past. A large mango tree that formerly housed many bats recently had been cut down. The nearby colonies of Fatai, Pea, Liahona, and Ha'ateiho may have absorbed some of the Tofoa bats.

Human predation and disturbance does not appear to be a problem in Tonga. Bats were very tolerant of people walking under roost trees (in some instances bats were only 5 m overhead) and loud noises (horns, car doors slamming shut) caused minimal disturbance. Roost site locations are consequently more stable in time and frequently occurred within villages on Tongatapu. In the Vava'u group, however, most roosts are located on west-facing ridges of islands. The prevailing winds are southeasterly and may be strong enough on occasion to cause the bats to choose locations with less wind. On a very windy day on Tongatapu, all bachelor males and most harem males and females abandoned exposed sites. When the winds subsided the following day, most bats returned to the formerly-occupied sites.

Fewer tree species were utilized as roost sites by *P. tonganus* in Tonga than in American Samoa. This might be an artifact of the highly modified vegetative cover on Tongatapu and my inability to identify most roost trees in Vava'u from a distant and unstable boat observation platform. Very little native vegetation remains on the relatively flat island of Tongatapu.

I witnessed interisland movements of flying foxes over relatively short distances (up to 8 km) in Tonga. Gill (1987) cited Rinke (1987) for observations of evening flights of bats from Kalau Island to 'Eua Island. However, Rinke (1987) reported bats on Kalau but did not present data on interisland flights. Rinke et al. (1992) reported flights between 'Eue'iki Island and Tongatapu Island. Locals reported seeing flights between 'Eua and Tongatapu Islands (20 km). Despite positioning myself in the evening to witness these latter flights, I did not observe any. *P. mariannus* is known to make longer flights between Guam and Rota, and perhaps other islands in the Marianas, in response to human disturbance (Wiles and Glass, 1990). Interisland flights in Tonga appear to be for foraging. The presence of *P. tonganus* on most large islands in Tonga and on many islands between Papua New Guinea and the Cook Islands (Miller and Wilson, 1997) suggests interisland flights have occurred frequently in the past.

Most species of flying foxes in Australia appear to have mating/nursery camps (roosts) separate from non-reproductive camps (Nelson, 1965). *P. tonganus* probably breeds year-round in Tonga as it clearly does in American Samoa. Volant young, non-volant young of all sizes, and mating vocalizations were heard in numerous colonies in Tonga (both on Tongatapu and Vava'u) suggesting that camps or roosts in Tonga are multi-purpose.

Flowers and fruit consumed on Tonga are similar to items utilized in American Samoa (Banack, 1995) and elsewhere (Wiles and Fujita, 1992). Few remains of food taken by bats under the roost trees were found. Numerous chickens and pigs foraged under bat roosts on Tongatapu and probably removed items shortly after they fell to the ground.

In summary, the population of *P. tonganus* in Tonga seemed robust and dispersed over many islands between 'Eua-Tongatapu in the south and Niuafo'ou in the north. This seems likely the result of the protection afforded to these "sacred" animals by the King of Tonga. The King and citizens of Tonga are to be commended for their attitude toward flying foxes.

ACKNOWLEDGMENTS

I am indebted to many Tongans for discussions about flying foxes: their lore, food habits, movements, and the location of roosts. Jim McMahon guided me to all of the island bat roosts in Vava'u. Funding for this study was provided by a Charles L. Cahill Award from UNCW and a grant from Bat Conservation International, Inc. S. A. Banack, K. M. Clark, and D. E. Wilson made suggestions improving this manuscript. To all of the above I am most grateful.

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Table 1
Flying Fox Roost Locations, Composition, Number of Trees Utilized, and Compass Orientation(Coastal Roosts) in the Kingdom of Tonga

Location	No. of Bats	No. of Trees	Compass Orientation (°)
Tongatapu Island			
Kolovai-Ha'avakatola	1,355	28	-
Tofoa	158	5	-
Ha'ateiho-Golf Course	549	3	-
Nuku'alofa	30	1	-
Matafanua-Liahona	75	many	-
Pea	400	several	-
Fatai	1,015	50	-
Ha'apai Group			
Lifuka	30	2	-
Vava'u Group			
Pangaimotu-Utelei	200	?	270
Pangaimotu-Utungake	40	3-4	270
Pangaimotu-Maungaui Pt.	60	several	270
Afo Island	25	?	340
Ofu Island	110	?	260
Manafa (Mafana) Island	350	?	330
Uta Vava'u-Makave #1	650	?	180
Uta Vava'u-Makave #2	600	?	270
Uta Vava'u-Makave #3	30	?	290
Uta Vava'u-Mt. Talau #1	6	?	280
Uta Vava'u-Mt. Talau #2	4	?	270
Tauta Island	40	?	330
'Eueiki Island	30	?	200
'Euekafa Island	40	?	270
Kapa Island-Mt. Teisina	1,200	?	260
Kapa Island-Muifaitunga	100	?	290
A'a Island #1	50	?	270
A'a Island #2	250	?	290
Kitu Island	300	?	250
Nua Papu Island #1	700	?	310
Nua Papu Island #2	2	?	310
Nua Papu Island #3	85	?	300
Nua Papu Island #4	30	?	280

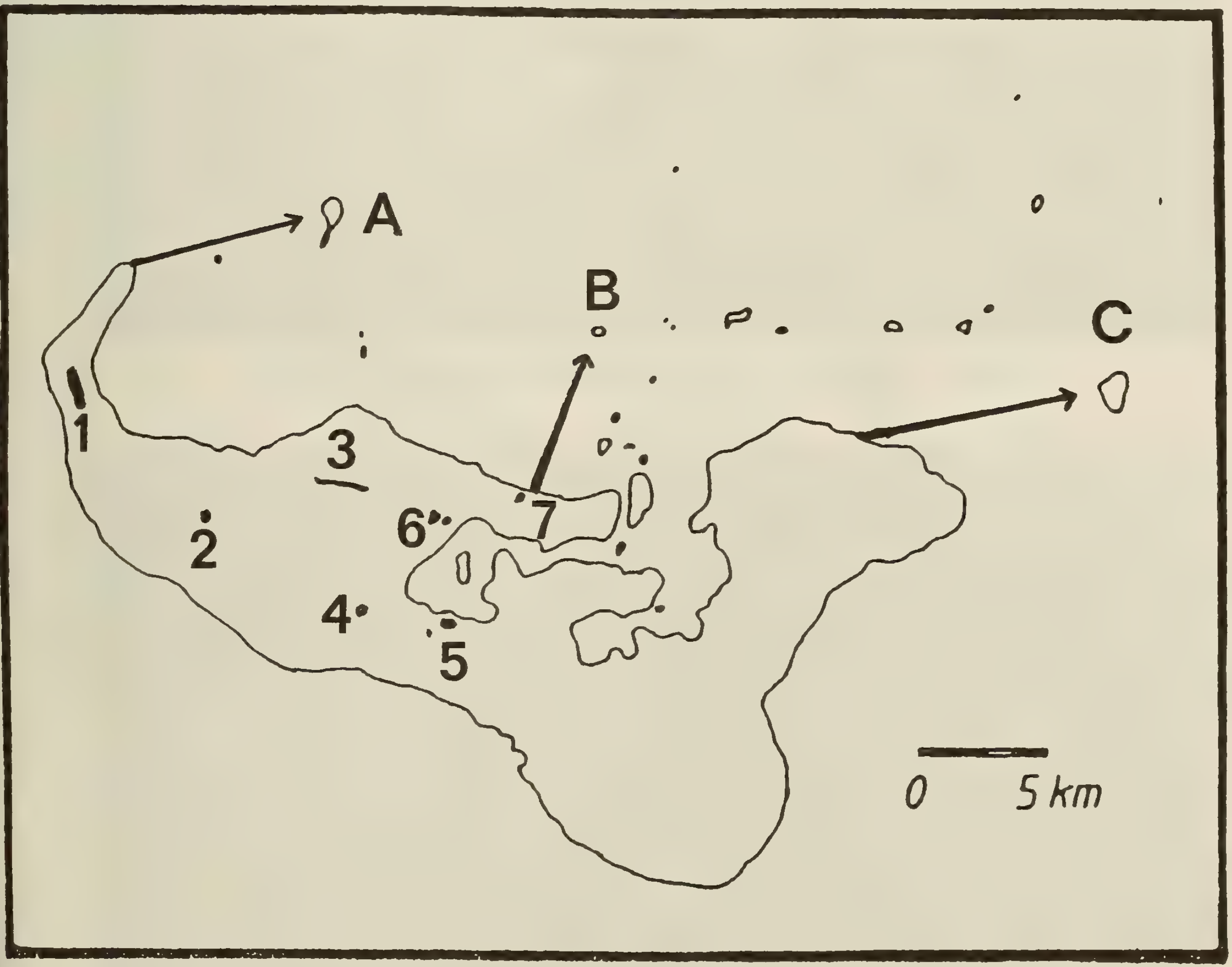
Table 1 (continued)

Nua Papu Island #5	3	?	270
‘aka’eitu (Vaka’eitu) #1	120	?	260
‘aka’eitu (Vaka’eitu) #2	600	?	280
Luakapa Island	300	?	?

Table 2
Tree Species Utilized as Roost Sites by *Pteropus tonganus* in Tonga

Tree Species	No. of bats Roosting in Trees	Percent of Total Bats	No. of Trees	Bats/Tree
Casuarina sp.	1581	45.3	26	60.8
Mangifera indica	792	22.7	8	99.0
Eucalyptus sp.	684	19.6	31	22.1
Ficus sp.	149	4.3	3	49.7
Cocos nucifera	147	4.2	12	12.3
Pisonia grandis	50	1.4	1	50.0
Terminalia catappa	50	1.4	1	50.0
Erythrina sp.	26	0.7	1	26.0
Ceiba pentandra	8	0.2	1	8.0
Cananga odorata	5	0.1	1	5.0
Total	3492	99.9	85	

Figure 4. Location of the seven major *Pteropus tonganus* roosts on Tongatapu, Kingdom of Tonga (1 = Kolovai-Ha'avakatolo, 2 = Matafanua-Liahona, 3 = Fatai, 4 = Pea, 5 = Ha'ateiho-Golf Course, 6 = Tofoa, 7 = Nuku'alofa). Direction of evening interisland feeding flights by bats are indicated by arrows to offshore islands (A = 'Atata, B = Fafa', C = 'Eue'iki).



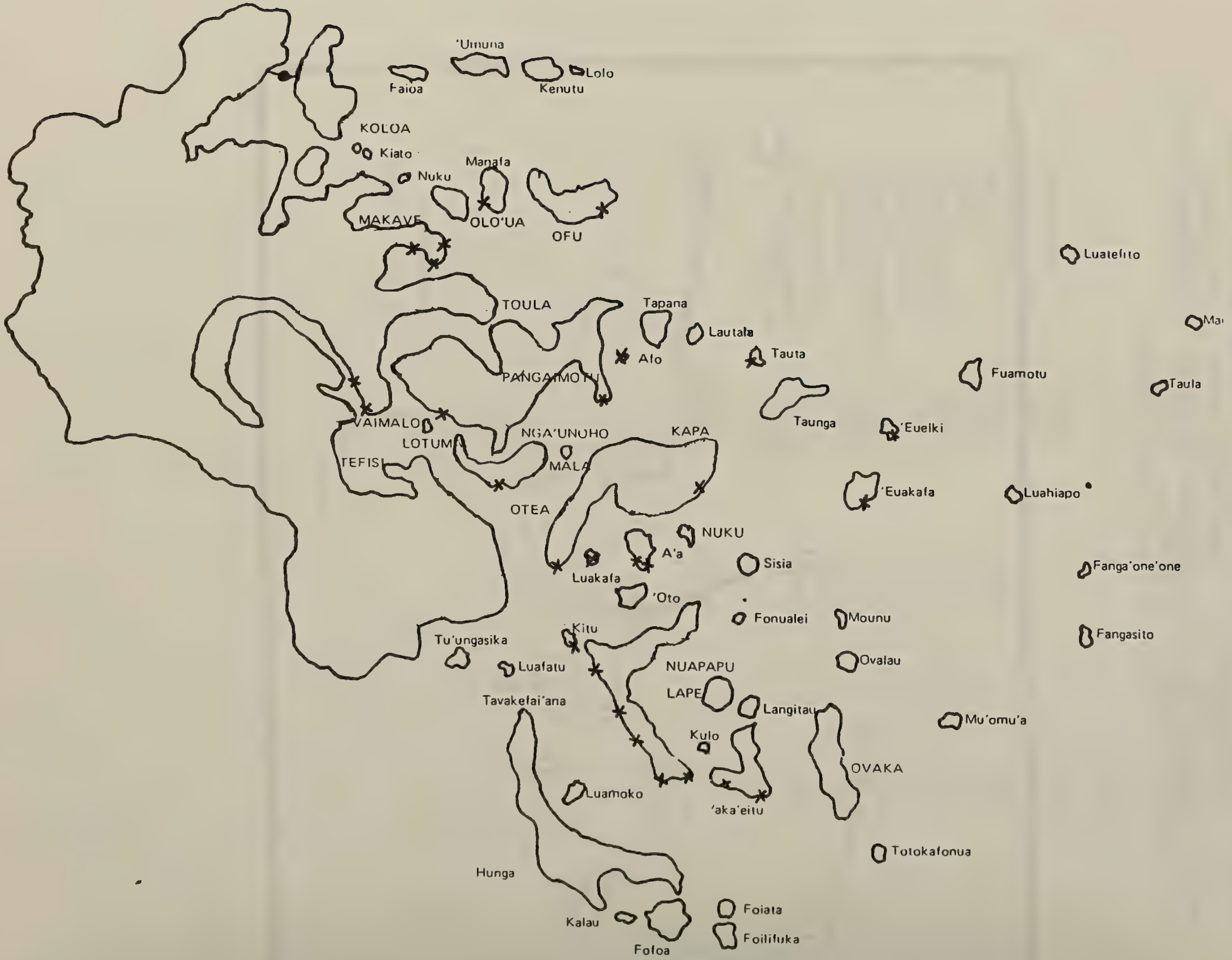


Figure 5. Locations (x) of *Pteropus tonganus* roosts in the Vava'u group, Kingdom of Tonga.

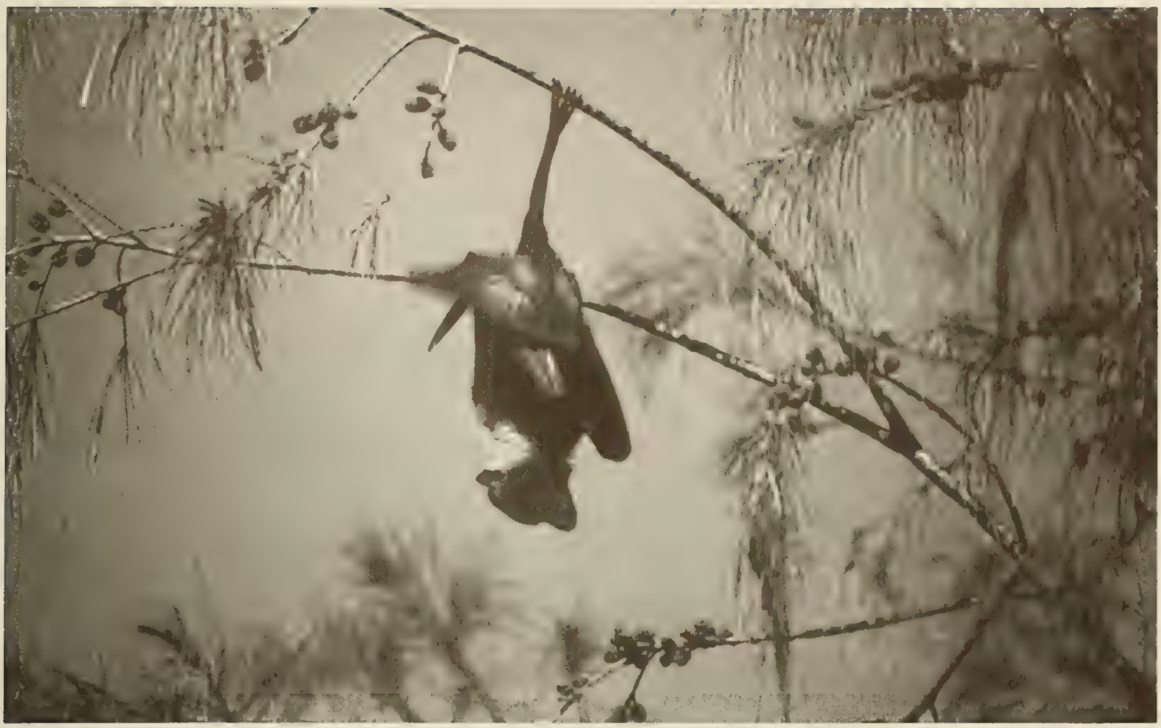


Figure 2. Pteropus tonganus in a roost on Tongatapu, Tonga.

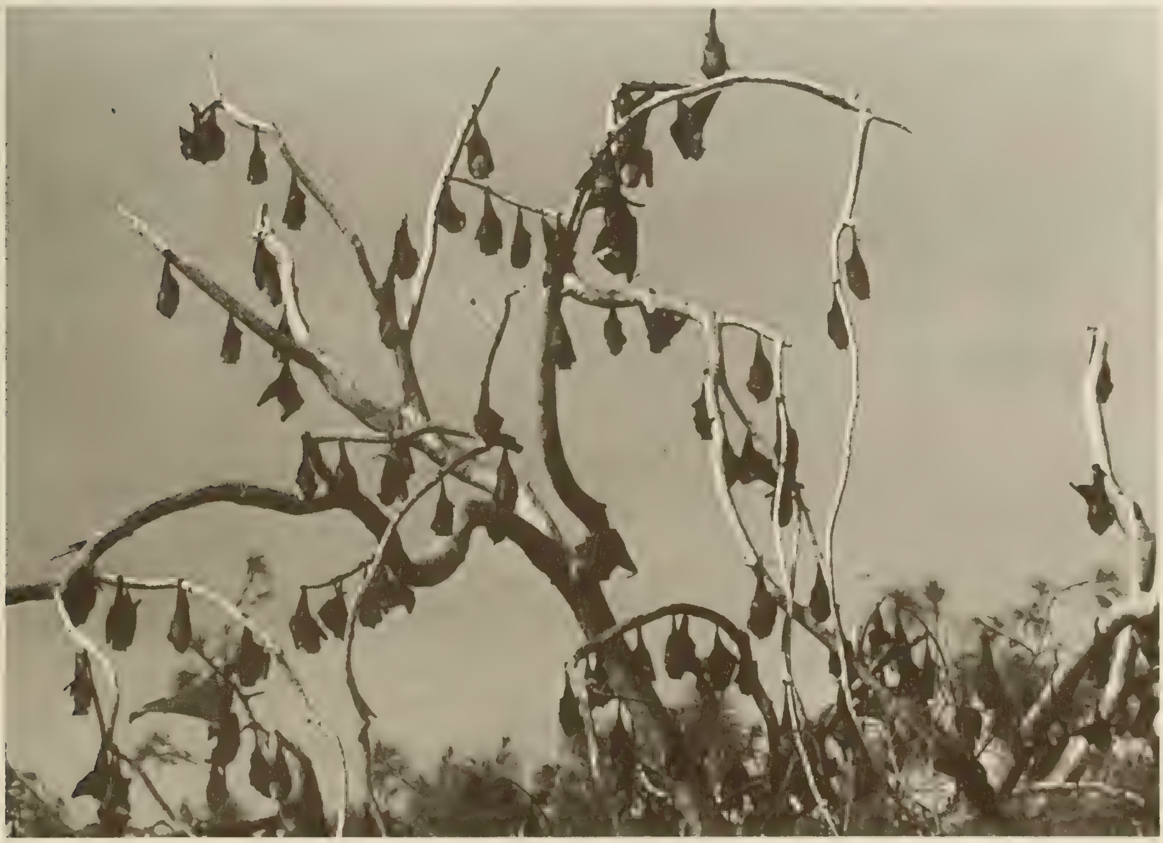


Figure 3. Portion of a roost used by Pteropus tonganus in Kolovai, Tonga.

ATOLL RESEARCH BULLETIN

NO. 455

NATURAL HISTORY OF BRAMBLE CAY, TORRES STRAIT

BY

JOANNA C. ELLISON

ISSUED BY
NATIONAL MUSEUM OF NATURAL HISTORY
SMITHSONIAN INSTITUTION
WASHINGTON, D.C., U.S.A.
SEPTEMBER 1998

NATURAL HISTORY OF BRAMBLE CAY, TORRES STRAIT

BY

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ABSTRACT

Bramble Cay, a small (3.6 ha) vegetated sand cay, is the most northern island of the Great Barrier Reef and the closest to the mouth of the Fly River. It has both volcanic rock and a reefal sand cay within its lagoon, and phosphatic rock exposures on the cay. The sand cay is the most important location for both seabird and turtle breeding in the Torres Strait and supports an endemic mammal, the rat *Melomys rubicola*. Records indicate that numbers of birds and rats have declined over the last century, possibly due to erosion and loss of vegetated area of the cay. The vegetation of the cay, made up of three herbs, is heavily disturbed by nesting activities. There is, however, a large and diverse drift flora, that is dominated by mangrove propagules exported from the Fly, that has no overlap with the cay's flora. Bramble Cay has a significant human history both from European exploration of the New Guinea coast, and from being the entrance marker to the Great North East Channel through the Torres Strait.

INTRODUCTION

Bramble Cay is the northern extremity of the Great Barrier Reef (GBR) before coral growth becomes limited by the discharge of the Fly, and is the northerly point of Queensland in the Torres Strait (9°08.6 S, 143°52.8 E, Figure 1). It is located 52.8 km SE of Kiwai Island, in the delta of the Fly River, Papua New Guinea (PNG), which carries an annual sediment load of 85 million tons year^{-1} (Harris, et al., 1993) Bramble Cay, however, has clear water and coral reef growth owing to passage of the Fly River plume to the north, tracking directly east along the PNG coastline (Harris, et al., 1993).

Of the island types found in the GBR, Bramble Cay (Plate 1) is within the category of low, vegetated sand cays modified by seabird activites described by Stoddart and Fosberg (1991) at Coombe, Michealmas, Raine, Stapleton and parts of Stainer, Morris and Magra. These are all located between 11-17°S; Bramble Cay is distinguished by its location in the wetter and biogeographically more diverse northern sector of the GBR. These types of islands feature patchy vegetation cover, with uncommon shrubs, and large bare areas resulting from seabird disturbance.

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Manuscript received 6 April 1998; revised 26 August 1998

The closest climate station to Bramble Cay is Daru (74 km to the west), which shows a mean annual rainfall of 2063 mm, and a range of 1163-3972 mm in the period 1894 to 1970 (McAlpine et al., 1983). Most rainfall occurs in the summer period, November to April. Southeasternly trade winds prevail from March to November, tending to send westward currents through the Torres Strait; the Northwest monsoon prevails December to March, tending to send an eastward current through the Strait.

Tides in the Gulf of Papua are semi-diurnal, with a mesotidal range of 2-2.5 m. Circulation in the Gulf of Papua is driven by tidal and wind-induced currents, influences the distribution of sediment load of the Fly along the coastal zone. The Fly has an annual freshwater discharge rate exceeding 235 km^3 (Alongi et al., 1992), carrying 85 million tons of sediment year $^{-1}$ (Harris et al., 1993), of which 47% is discharged from the delta. This sediment is largely carried northeast from the delta and along the coast of the Gulf of Papua, except during the southeast trade wind season, when a small proportion of discharge from the Fly traverses west from the delta and along the southern coastline of PNG (Harris et al., 1993).

GEOLOGY AND GEOMORPHOLOGY

The island rises from water depths of 35 m to an oval reef 1.8 x 0.9 km (Figure 2). It is of volcanic origin, demonstrated by exposures of Pleistocene Maer volcanics in the lagoon (Jardine, 1928; Willmott, et al., 1973). Similar exposures occur at several locations in the NE Torres Strait, at the Murray, Darnley and Stephens Islands, and the Black Rocks 6.5 km to the SW of Bramble Cay. They result from subaqueous emission of basaltic lava, that subsequently was deeply eroded. The largest exposure (about 40 x 40 m) in the Bramble Cay lagoon is shown in Plates 1 and 2.

The sand cay occurs at the western margin of the lagoon, 330 m NW of the large volcanic outcrop, and has a vegetated area of 175 x 76m. It is composed of foraminiferal sand, with some coral and shell fragments (Jardine, 1928), with an exposure of phosphatic rock on the southeast shore (Figure 3, Plate 3) that rises to 1.9 m above HTM. The vegetated area has several raised ridges and lower pools which collect rainwater (Plate 1). Stratigraphy was examined at two locations. Location 1, on a ridge in the southeast of the island, showed 14 cm of organic peat above hard phosphatic rock. Location 2, adjacent to a pool in the center of the island, showed 22 cm of peat above 40 cm of loosely cemented calcareous sand. This is similar to stratigraphy reported from Raine (Stoddart et al., 1981) of moist black peat above calcareous rubble.

In 1862 a mining lease was granted to the Anglo-Australian Guano Company (Crowther, 1939), and occasional boats mined the low grade phosphatic rock (Jardine, 1928). The quality was poor enough to ensure that a base was not established as at Raine (Stoddart et al., 1981), and areas of rock remain today. There is an exposure at the eastern end of the cay (Figure 3, Plate 3). A sample of this rock was analysed, and compared with a surface soil sample from the interior of the cay. Samples were treated with perchloric/ nitric acid and analysed by ICP-AES. Owing to their high carbonate and phosphatic content, they were diluted for verification. Results are given in Table 1.

Stoddart and Scoffin (1983) reported levels of phosphate of 7.8-35.1% from rock on Raine, demonstrating the lower grade quality of the Bramble Cay rock. This is probably because Bramble Cay receives substantially more rainfall than Raine.

Coal is commonly found on Bramble Cay, both inland on the surface and exposed in wave eroded sand cliffs. Plate 4 shows these as wave-rounded and cobble sized. The source is ships wrecked on the island (Table 2), the most likely being either the *Windhover* (1889) or the *Mutlah* (1915). Both are discussed in the next section.

EARLY HISTORY

The chronology of human visits to the island is given in Table 2.

Customary tenure of Bramble Cay is held by the inhabitants of Darnley Island, 45 km to the southwest. The islanders' legend of Rebes describes how Darnley people, using soil rafted from Darnley, built Bramble Cay to provide turtle eggs and meat in season. Having deposited the soil to form the Cay, the wind veered and strengthened, and four villagers were fixed to form the volcanic rock outcrop, and the rest formed the (phosphatic) stone on the sand cay (Haddon, 1935). Darnley Islanders travel to Bramble Cay to collect turtle and bird eggs during the nesting season, and also grant inhabitants of other islands permission to collect (Johannes and MacFarlane, 1991).

The island was named after the *HMS Bramble* which under the command of Lieutenant C. B. Yule, was engaged in survey work in the Torres Strait and the southern coast of Papua New Guinea in 1843 and succeeding years (Jukes, 1847). Accounts of these early visits provide information about the island's earlier history and ecology. The *Fly* visited Bramble Cay on 6 May, 1844, and Jukes comments:

> The sand-key on one side of the reef was precisely similar in appearance and structure to Raine's Islet, except that it was much smaller. It equally abounded in "spinach" and bird's eggs, and any ship coming in from the Pacific in want of fresh provisions might get enough for some days' consumption by stopping there, taking care to break all the eggs on the island as soon as they arrive, in order to have new-laid ones to carry away with them (Jukes, 1847).

When the *Bramble* returned to Bramble Cay in April 1846, a junior officer remarked that Mr. Yule considered it to be a good anchorage "because it was free from natives of whom he entertained the greatest horror. Here besides a good supply of eggs and spinach we also obtained 5 turtle" (Sweatman, 1977). The anchorage was returned to on 3 June, after a survey of the south coast of New Guinea. The ship remained 5 days to obtain observations for rating the chronometers, and took advantage of the stay to obtain a good supply of eggs (Sweatman, 1977).

During the visit of the *Rattlesnake* 16-19 December 1849, tern and booby eggs were smashed and gathered, and a total of 18 turtles were taken (Huxley, 1935). Huxley comments: "The spinach to my mind is filth; others like it however."
MacGillivray (1852) comments from the same visit:

> In the afternoon I landed for an hour, passing many turtle on the water both going and returning. As usual the island was covered with sea birds, only two species, however, of which were breeding. The Brown Booby (*Sula fusca*) and a large tern (*Thalasseus pelecanoides*) existed in about equal numbers....As the tern eggs were within a short time of being hatched we broke all we saw in order to ensure some newly laid ones in a day or two...
>
> The Golden Plover was plentiful on the island during our visit, and one afternoon I killed fifteen in about an hour...
>
> The weed which in the *Fly* we used to call spinach (a species of *Boerhaavia*, actually *B. duffusa*) being in abundance here, was at my suggestion collected in large quantity for the use of the ships company as a vegetable, but it did not seem to be generally liked.

In 1889 four ship wrecks occurred on the island (see Table 2). The Master of one requested in a letter to *Nautical Magazine* that a lighthouse be located on the cay (Planck, 1889). He stated that the island is at the entrance to the N.E. channel, is difficult to see owing to its low elevation, and because strong and irregular currents occur in the area. The *Windhover* went ashore on the cay in August 1889 while carrying coal, and was abandoned. This wreck could have contributed some of the coal found today on the cay.

A James Nourse steamer, the *Mutlah*, went aground at Bramble Cay on 28/8/1915 on a voyage from Port Kembla to Colombo. It was refloated on 13/9/15 (John Foley. pers. comm), apparently after some thousands of tons of coal had been jettisoned. This coal is referred by Rev. Done, who visited the island on the *Herald* in 1917, and used some of the coal for fuel (Done, 1987).

Done (1987) was not there in the turtle breeding season, so "On this occasion we had to be content with terns' eggs and secured a large quantity........They were subsequentely used boiled, fried, scrambled or in omelette form, and were not in the least fishy in flavour."

Bramble Cay was heavily exploited in its early history for bird and turtle eggs by both European and Torres Strait Islander visitors. The effects of this exploitation on breeding colonies are discussed in the fauna section below.

Lighthouse History

Bramble Cay, marking the northern entrance to the Great North East Channel through the Torres Strait, is today dominated by a lighthouse (Plate 5). From 1890 it was the boarding ground for pilots to guide sailing vessels through the channel to Thursday

Island (Davenport, 1986). This followed a series of shipwrecks on the cay (Table 2), and requests for a lighthouse (see previous section).

Done records in 1917 that "according to a chart there is a beacon 45 ft high. But that beacon has long been in a recumbent position, and is of no value to mariners. It is whispered that there is some talk of an unattended light being placed there...."

In 1924 (24 October) a 42 ft pyramidal steel tower was erected. Jardine (1928) showed this as located in the central eastern end of the island (Figure 6). There are no remains of this tower today. According to A.M.S.A. records it was razed in 1954 and replaced by the present lighthouse, though Limpus et al. (1983) reported that a temporary scaffold with four wire guys was erected at the southeastern end of the cay in 1958. The remains of this structure can be found on the beach at the southeastern end (Fig. 3, Plate 6), the island having moved to the northwest.

The present lighthouse, a 17 m stainless steel tower, was converted to solar power on 6 January 1987. The lighthouse was never manned, but is maintained by A.M.S.A. vessels every 3-6 months.

MOVEMENT OF THE CAY

Figure 4 shows changes in shape of Bramble Cay between 1978-1979 when it was mapped by Applied Ecology (Parmenter, 1980), and 1994-5 when it was mapped by the author using tape and compass techniques. Other detailed surveys of the island exist that could not be incorporated into this map. Jardine (1928) provided a map of the island from his visit in September 1924 (Figure 6), but the remains of the lighthouse shown on this map could not be located in 1994-5, hence there is no common reference.

In 1924 the area of the cay within the tidal level shown by Jardine (1928) was 395 x 183 m. Limpus et al. (1983) record the dimensions of the island at spring high tide level in December 1977 and 1978 as 340 x 150 m. Parmenter (1980) mapped the island area above high tide as 281 x 128 m in October 1978, and 223 x 112 m in March 1979. In January 1987 the dimensions of the island above high tide were 320 x 130 m (Walker, 1988); in February 1994 it was 272 x 126 m and in February 1995 it was 251 x 104 m. The area of the island in 1995 was 1.72 ha in vegetated area, and 3.62 ha above high tide mark.

Limpus et al. (1983) concluded that the cay was moving towards the northwest, and losing sand over the edge of the reef flat (see Fig. 2). Parmenter (1980) showed that during the south-easterlies (winter) sand is deposited at the northwest shore of the cay, which is eroded during the north-westerlies (summer). Figure 4 shows that the shape of the cay has not substantially changed since the 1970's, the most significant change being reduction in vegetated area.

In 1924 the vegetated area was 295 x 146 m at its widest dimensions (Jardine, 1928); in 1978-79 it was 170 x 97 m (Parmenter, 1980); in January 1987 it was 215 x 100 m (Walker, 1988); and in 1994-5 it was 175 x 76 m. Figure 4 shows that most of the loss has been from the south and north shores. Plate 7 shows how the vegetation margins are limited by the activites of turtle nesting. A former control on turtle nesting would have been cliffs of phosphatic rock, the historic removal of this would make more island area accessible. The main control today is turtle access. Turtle breeding occurs in the summer period, when the island is being eroded from the northwest. Plate 8 shows the sand cliff that develops, which discourages turtles from coming ashore. Many failed attempts were witnessed at night in February 1995. The turtles would move along the shore and successfully cross the beach on the gentler graded south or north shores. The east shore is somewhat protected from turtles by the phosphatic rock outcrop cliffs.

The reliability of Jardine's measurement techniques is demonstrated by his detailed map of the volcanic rocks in the lagoon. Therefore his map of the cay can be used as strong evidence that the island has substantially eroded this century. The area within high tide levels is more variable (Figure 4) with seasonal prevailing wind, but the vegetated area has consistently declined.

WATER

Water collects in pools on Bramble Cay after rainfall and can remain for several days. Water samples were tested in February 1995 from two locations: 1 was the large pool in the NE of the cay (Figure 5, Plate 5), and 2 was the large pool SE of the lighthouse (Figure 5, Plate 7). Results in Table 3 show that surface pools are of fresh water.

VEGETATION AND FLORA

The vegetation of Bramble Cay consists of low herbaceous cover (Plates 1 and 5), greatly disturbed by nesting activities of birds and turtles. Species present in 1994-5 and past records are summarised below. Nomenclature follows Fosberg and Stoddart (1991).

AIZOACEAE

Sesuvium portulacastrum (L.) L.
Limpus et al. (1983) sight.

AMARANTHACEAE

Amaranthus viridus L.

Parmenter, s.n. (January, 1984); Queensland Herbarium s.n. (in Walker, 1988); Walker (1988); Ellison 1002, 1003, 1005.
This erect or decumbent annual with weedy habit was occasional on Bramble Cay in 1994 and 1995.

ARECACEAE (PALMAE)

Cocos nucifera L.
Walker, sight (dead). Drift seeds were present in both 1994 and 1995 (see later section), but none established. Coconuts have been planted on the island by visitors, but have not survived long (Walker, 1988).

CONVULVULACEAE

Ipomoea pes-caprae (L.) R. Br.
Queensland Herbarium s.n. (in Walker 1988).

CYPERACEAE

Cyperaceae indet.
Queensland Herbarium s.n. (in Walker 1988).

NYCTAGINACEAE

Boerhavia tetrandra sensu Walker non Forst. f.
MacGillivray (1852) sight; Queensland Herbarium s.n. (in Walker 1988); Limpus et al. (1983) sight; Parmeter (1980) sight; Ellison 1001, 1004.
The dominant cover on Bramble Cay, as found by all visitors. This is the "spinach" gathered and eaten by early European visitors (MacGillivray, 1852; Sweatman, 1977). Forms a lush and dense cover up to 40 cm in height, especially on raised and better drained areas of the cay.

POACEAE (GRAMINEAE)

Cenchrus echinatis L.
Queensland Herbarium s.n. (in Walker, 1988).

Lepturus repens (Forst. f.) R. Br.
Queensland Herbarium s.n. (in Walker, 1988). Limpus et al. (1983) sight; Parmeter (1980) sight; Ellison, 1006.

Not found by Walker in January 1987, but by February 1995 had reestablished on the north shore of the cay.
Poaceae indet.
Walker, 1988. Unidentified grass found both in January 1984 by C.J. Parmeter and January 1987 by T.A. Walker. Not present in 1994-5.

PORTULACEAE

Portulaca oleracea L.
Parmeter, 1984, sight; Walker, 1987. Not present in 1994-5.

ZYGOPHYLLACEAE

Tribulus cistoides L.
Queensland Herbarium s.n. (in Walker, 1988).

There are records of 11 species of flora from Bramble Cay, but only 3 were found in 1994-5, *Boerhavia tetrandra* , *Amaranthus viridus* and *Lepturus repens* . Limpus and Parmenter found 5 species in 1984, and Walker found 4 species in 1987 (Walker, 1988). The record for *Lepturus repens* indicates that species may be lost from the cay and re-establish, and the later section on drift seeds indicates that there is a plentiful and diverse supply of seeds.

There is intense disturbance of the periphery of the vegetated area of the cay from the nesting activities of turtles, illustrated in Plate 7. Figure 4 shows change in the vegetated area of the cay from 1983 to 1995, indicating that the area has been substantially reduced. This provides an explanation for the reduction in species numbers recorded here.

FAUNA

Coral

The coral communities at Bramble Cay were surveyed by Babcock (1988), who found 117 species, and described coral communities as a mixture of inshore types (of more turbid water), and those more typical of exposed mid and outer shelf reefs of the central GBR. This is due to the combination of proximity to the Fly and exposure of the island to southeasterly swell fom the Coral Sea (see Fig. 1).

Some dead coral seen during the survey was attributed to predation by the crown-of-thorns *Acanthaster planci*, of which 7 were observed.

Birds

Bramble Cay is a major breeding colony for seabirds in the Torres Strait islands (Cameron, et al., 1978), particularly Sooty Terns, Crested Terns, Common Noddies and Brown Boobies. Draffan et al. (1983) show a total of 24 species in a summary table, but only 20 species are named as present on Bramble Cay in the listings by species. Walker (1988) recorded 10 species present in January 1987. On 19 February 1995 there were 11 species present, of which one was a new one for the island (Black-Fronted Dotterel). There have been a total of 23 birds recorded on the island, of which one is almost certainly a mistake (Lesser Noddy).

ALCEDINIDAE

Halcyon sancta Sacred Kingfisher

Recorded by Draffan et al. (1983), a common passage migrant and winter resident in the Strait.

ARDEIDAE

Egretta sacca Eastern Reef Egret

Recorded by Draffan et al. (1983) as breeding during the wet season. Walker (1988) recorded 2 on the volcanic rocks. On 19 February 1995 there was 1 present on the rocks.

Nycticorax caledonicus Rufous Night Heron

Recorded by Draffan et al. (1983), common in the Strait. Walker (1988) recorded 1 on the volcanic rocks. Not recorded on 19 February 1995.

CHARADRIIDAE

Pluvialis dominica Lesser Golden Plover

Recorded by Draffan et al. (1983), common in the Strait. Walker (1988) recorded 20 present. On 19 February 1995 there was one present on the beach, in non-breeding plumage. MacGillivray (1852) records that they were plentiful on the Cay in December 1849, such that he was able to kill 15 in about an hour. Done (1987) notes "half a dozen Plover" present in September 1917.

Charadrius mongolus Mongolian Plover

Recorded by Draffan et al. (1983), common in the Strait. Not recorded by Walker (1988) or in February 1995.

Charadrius melanops Black-Fronted Dotterel

On 19 February 1995 4 were seen feeding in mud areas adjacent to a freshwater pool. This species is previously unrecorded on Bramble Cay.

Subfamily CIRCINAE

Circus assimilis Allied Harrier
MacGillivray (1914) records this present at Bramble Cay on 27 July 1911.

COLUMBIDAE

Ptilinopus superbus Superb Fruit Dove
Recorded by Draffan et al. (1983), nocternal movement across the Strait September to April, not breeding.

FREGATIDAE

Fregata ariel Lesser Frigatebird
MacGillivray (1914) recorded 2 present at Bramble Cay on 27 July 1911. Draffan et al. (1983) recorded presence, but not breeding. Walker (1988) recorded 12 circling overhead or roosting on the volcanic rocks. On 19 February 1995 there were 20 circling overhead or roosting on the volcanic rocks.

Fregata minor Greater Frigatebird
Draffan et al. (1983) recorded presence, but not breeding. Not recorded by Walker (1988) or in February 1995.

LARIDAE

a) Noddies

Anous stolidus Common Noddy
MacGillivray (1914) records these as 'very numerous" at Bramble Cay on 27 July 1911. Draffan et al. (1983) record that more than ten thousand birds breed at Bramble Cay during the wet season. However, in January 1987 Walker (1988) recorded only 30, with 10 unfledged juveniles on the eastern end of the cay, noting that this was not the peak of the breeding season. On 19 February 1995 approximately 3300 were present, with nesting colonies dispersed across the cay (Figure 5). These were in raised and vegetated areas, and occasionally shared the nest of *Sula leucogaster*.

Anous tenuirostris Lesser Noddy
Noted by Draffan et al. (1983) as probably an erroneous record made by Masters (1875), an error for *Anous stolidus*.

b) Terns

Sterna bergii Crested Tern

MacGillivray (1914) records 'great numbers" present at Bramble Cay on 27 July 1911, but not breeding. Draffan et al. (1983) record that over a thousand pairs nest regularly from December to March, despite human predation. Walker (1988) recorded approximately 1800 nests in 4 large colonies on the eastern end of the cay. On 19 February 1995 this was the most common bird present on the cay, with approximately 6400 present in nesting colonies (Figure 5), with the largest colonies at the northwest end and the northeast end surrounding a freshwater pool. The Crested Tern colonies were in lower elevation, unvegetated locations adjacent to areas that flooded after rainfall.

Sterna fuscata Sooty Tern

MacGillivray (1914) records "great numbers" present at Bramble Cay on 27 July 1911, with two small colonies of fledged young. Draffan et al. (1983) recorded this as the most common species at Bramble Cay, with 40,000 breeding in the summer, despite heavy human predation. Walker (1988) recorded 700, with 300 nests containing eggs. On 19 February 1995 there were approximately 1300 present, in four separate colonies on the northwest end of the cay (Figure 5). Like the Crested Terns, the Sooty Terns nested in lower elevation areas.

Sterna hirundo Common Tern

Recorded by Draffan et al. (1983), noted as an uncommon summer visitor to the Torres Strait. They were not recorded by Walker in 1987; on 19 February 1995 there were 10 present.

Sterna anaethetus Brindled Tern

10 pairs are recorded by Draffan et al. (1983) as breeding on Bramble Cay. Not recorded by Walker (1988) or in January 1995.

c) Gulls

Larus novaehollandiae Silver Gull

Recorded by Draffan et al. (1983), who notes that the species breeds on small islands during the winter months. Walker (1988) recorded 24 present. On 19 February 1995 there were 10 present.

PHAETHONTIDAE

Phaeton lepturus White-tailed Tropicbird

Vagrant seen at Bramble Cay November 1989 (Draffan et al., 1983).

PLATALEIDAE

Threskiornis eathiopica Sacred Ibis

Recorded by Draffan et al. (1983), who notes that the species is an irregular visitor to eastern islands.

SCOLOPACIDAE

Arenaria interpres Ruddy Turnstone

Recorded by Draffan et al. (1983), passage migrant found throught the Strait. Walker (1988) recorded 50 present. On 19 February 1995 there were 30 seen on the beach, in breeding plumage.

Tringa brevipes Wandering Tattler

Recorded by Draffan et al. (1983), uncommon migrant.

STURNIDAE

Aplonis metallica Metallic Starling

Recorded by Draffan et al. (1983), nomadic in the Strait.

SULIDAE

Sula leucogaster Brown Booby

MacGillivray (1914) records only two nests present at Bramble Cay on 27 July 1911, but notes that this was just after a major feast by visiting islanders. Draffan et al. (1983) recorded that about 10 pairs breed on Bramble Cay during the wet season, and cites a report of breeding in July. Walker (1988) recorded 70 present. On 19 February 1995 there were 92 present, nesting in raised vegetated areas mostly on the north and east sides of the island (Figure 5).

Patterns in the bird communities

Bird nesting was limited at its outer perimeter by turtle nesting disturbance, which also controlled the outer limit of vegetation, shown in Figure 5. Turtle nesting activities were limited by occurrence of phosphatic rock. Most bird nesting was on the north side of the cay, with virtually no nesting on the south side, as shown in Figure 5. There was microelevational control of nesting patterns, with Terns nesting in lower elevation areas and Noddies and Boobies nesting in areas of raised elevation. The lowest areas were not used because these flood and hold pools of water after rainfall. Sooty Terns only nested on the west end of the cay in 1995, Walker (1988) recorded in 1987 that they only nested on the eastern end.

Walker (1988) comments on the impact of human predation on bird numbers, particularly on Brown Boobies which have a longer incubation and fledgeling period. Early ships visiting the island commonly smashed all eggs in order to gather fresh ones the next day (Jukes, 1847; Huxley, 1935; Sweatman, 1977). Johannes and MacFarlane (1991) describe the traditional harvesting of Boobies, Terns and Noddies, and their eggs by Darnley Islanders on Bramble Cay. Thousands of eggs could be collected on one trip by Darnley islanders, and frequently 14 or 15 turtles are brought back in addition. Walker (1988) witnessed thousands of eggs removed by people who arrived in speedboats from Stephens Island. The Booby numbers recorded in February 1995 were higher than other recent records (Draffan et al., 1983; Walker, 1988), but far less than the records of early ships visiting the cay. MacGillivray (1852) from a visit in December 1849 records Boobies nesting in equal numbers to Terns.

Turtles

Bramble Cay is one of Australia's larger green turtle (*Chelonia mydas*), rookeries (Limpus, 1981), though numbers recorded are variable. The nesting season in the Torres Strait is approximately October to February (Kowarsky, 1978).

In the early 1970's a federally-funded project by Applied Ecology Pty. Ltd. attempted to establish turtle farming in the Torres Strait islands. A research team spent 3 seasons (Oct-March) on Bramble Cay studying breeding habits (Onions, 1979), and turtle eggs from Bramble Cay and other islands were gathered to establish commercial turtle farms on inhabited islands (Kowarsky, 1977; Johannes and MacFarlane, 1991). Applied Ecology built a house on the southwestern end of the island, the foundations of which were still there in 1995 (Figure 3). The project had failed by 1980 owing to insufficient research and economic inviability (Johannes and MacFarlane, 1991).

Over their two years research Applied Ecology found a maximum nightly count of 60 turtles nesting. Numbers were generally lower: Kowarsky (1978) recorded 1 turtle nesting on 7 November 1975, and 9, 4 and 5 nesting on the nights 3-5 January 1976. The maximum count was Walker (1988) in January 1987, who recorded a minimum of 290 nesting. From 17-19 February 1995, 20 and 24 turtles nested each night, which was relatively low numbers.

As well as harvesting of bird eggs, early ships (see Table 1) visiting Bramble Cay commonly took turtles (MacGillivray , 1852; Sweatman, 1977; Done, 1987). Limpus (1980) noted that with all the taking of green turtles in the GBR area since European colonisation, Bramble Cay is the only island with evidence of a major decline in nesting populations. Parmenter (1980) commented that in the early 1970's government social programmes permitted dinghy/ outboard ownership beyond Thursday Island to allow easier turtle harvest in the Bramble Cay area of the Torres Strait.

Rats

Sweatman in April 1845 describes a number of large rats that ran from under dead turtle shells. This is *Melomys rubicola*, an endemic rodent that is only recorded on Bramble Cay, first described by Thomas (1924) from a specimen collected by MacGillivray in May 1845.

In 1977 and 1978 Limpus et al. (1983) describe several hundred rats as present, foraging in the vegetation at night. They found no evidence of the rat preying on eggs or young birds on the island. Walker (1988) found only one mother with two young near the lighthouse, though he did not visit after dark, when the rats are active.

In February 1995 rat tracks were seen around a small cave entrance beneath the phosphate rock on the southeast shore of the island, close to the 1958 lighthouse base. Tracks could be seen leading into fresh turtle nests, suggesting that the rats may not be vegetarian as was previously thought (Limpus et al., 1983; Walker, 1988). Nests with rat tracks approaching had uncovered and broken turtle eggs. On the night of 16/2/96 the *R/V Harry Messel*'s engineer reported seeing rats feeding on turtle eggs (Craig Rawson, pers. comm.). Despite a search for two nights with torches, this was the only individual seen during the visit, suggesting that numbers are much reduced from the 1970's.

DRIFT DISSEMENULES

The diversity of species occurring on Bramble Cay as drift seeds was considerably more than that of the island's flora, with no common species. All seeds stranded during low tide on 6 Febraury 1994 and 17 February 1996 were collected and identified. Results are given in Table 4.

In 1994 (6 February) the shoreline length was 886 m, and there were a total of 647 drift seeds, of which 79% were mangrove. This gave a seedling density of 0.73 seeds/m. In 1995 (17 February) the shoreline length was 809 m, and there were a total of 3206 drift seeds, of which 81% were mangrove. This gave a seed density of 3.96 seeds/ m.

In addition to seeds, there was a diversity of other debris along the strand-line, including whole *Nypa* trees, other large tree trunks, old turtle eggs, pumice, *Sargassum* seaweed, cuttlefish and coal. There were mangrove plant parts such as *Bruguiera* buds, *Sonneratia* and *Bruguiera* flowers, and *Rhizophora* leaves.

The domination of Bramble Cay's drift flora by mangroves, particularly *Nypa,* suggests a source from the Fly River. Sedimentation studies by Harriss et al. (1988) showed that the vast majority of discharge of the Fly is carried northeast from the delta and along the coast of the Gulf of Papua. During the southeast trade wind season, a small proportion of discharge from the Fly traverses west from the delta and along the southern coastline of PNG. Both drift seed counts here were from February, when prevailing Northerlies should keep Fly discharge from affecting Bramble Cay. The drift species and quanitity, however, suggest that large amounts of debris from the Fly are caught in eddies away from the main direction of the plume, to deposit material on Bramble Cay.

During the author's visits to Bramble Cay the Australian Institute of Marine Science cored several large *Porites* colonies. Data shows complex interactions between river plumes and coral crowth band fluorescence, as well as stable isotope and trace element variations thought to be associated with sea surface temperature (Gregg Brunskill, pers. comm. 8/98). This confirms the drift seed record that Fly discharge influences Bramble Cay.

CONCLUSION

This review has established that for its small size (3.62 ha), Bramble Cay has particular interest in its location and geomorphology, flora and fauna, and human history. It is both the most northern island of the Great Barrier Reef and the closest to the mouth of the Fly River. It has both volcanic rock and a reefal sand cay within its lagoon, and phosphatic rock exposures on the cay.

Records show 23 species of seabirds on the sand cay, and it is a major breeding location for Crested and Sooty Terns, Common Noddies and Brown Boobies. It is one of Australia's most important green turtle rookeries, and also has an endemic mammal, the rat *Melomys rubicola*. Records indicate that numbers of birds and rats have declined over the last century, possibly due to erosion and loss of vegetated area of the cay. The vegetation of the cay is heavily disturbed by nesting activities, and is limited to three herbs, though there are records of eleven in total over time. There is, however, a large and diverse drift flora, dominated by mangrove propagules exported from the Fly, that has no overlap with the cay's flora.

Bramble Cay has a significant human history both as a site of European exploration of the New Guinea coast, and as the entrance marker to the Great North East Channel through the Torres Strait. It has records of five shipwrecks that have resulted in significant deposits of coal on the cay. and a history of four lighthouses which are lost over time due to movement of the cay.

ACKNOWLEDGEMENTS

The opportunity to visit Bramble Cay in 1994 and 1995 was provided by Dr. Gregg Brunskill of the Australian Institite of Marine Science, and the Masters and crews of the *R/V Lady Basten* and *R/V Harry Messel*. I thank Dr. Betsy R. Jackes and Mr. Osia Gideon of the Department of Botany, James Cook University, for assistance in identification of seeds. I am indebted to Capt. John Foley of the Torres Strait Pilot Service for information on the grounding of the *Mutlah*. This research was undertaken during tenure of an Australian Postdoctoral Research Fellowship.

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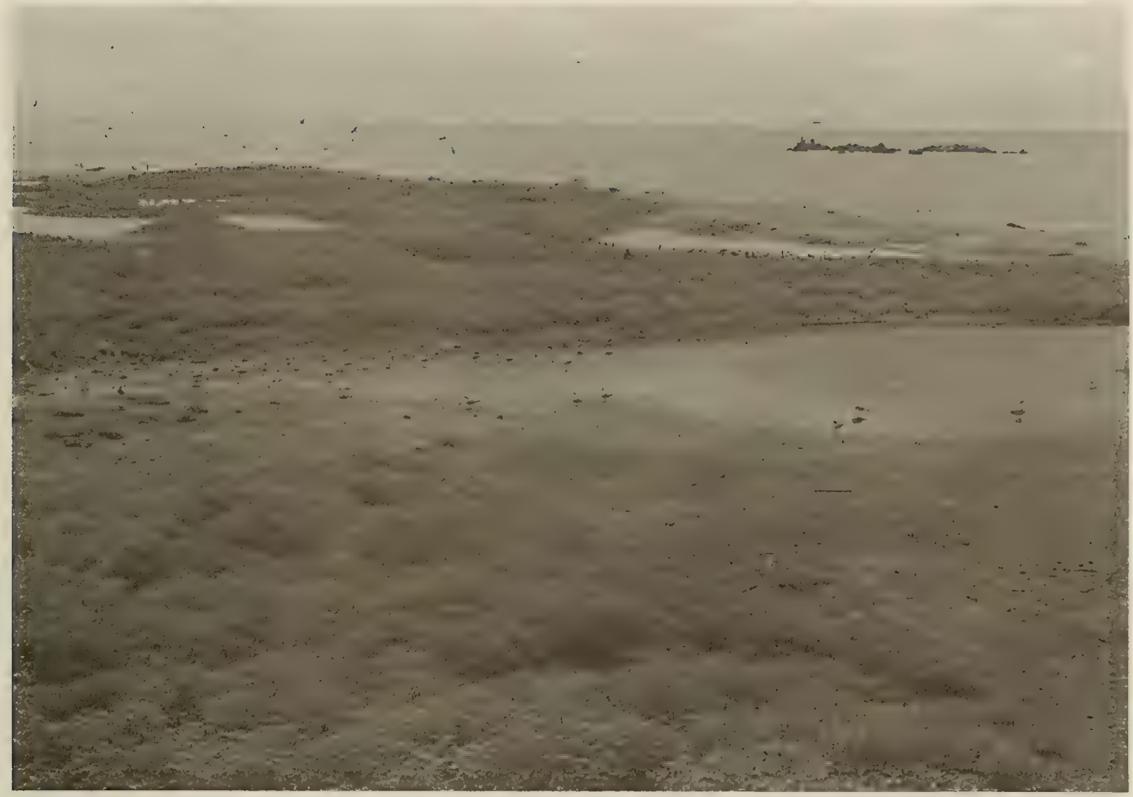

Plate 1. Bramble Cay, showing low herbaceous vegetation, tern rookeries adjacent to water pools, and volcanic rock offshore in the lagoon.

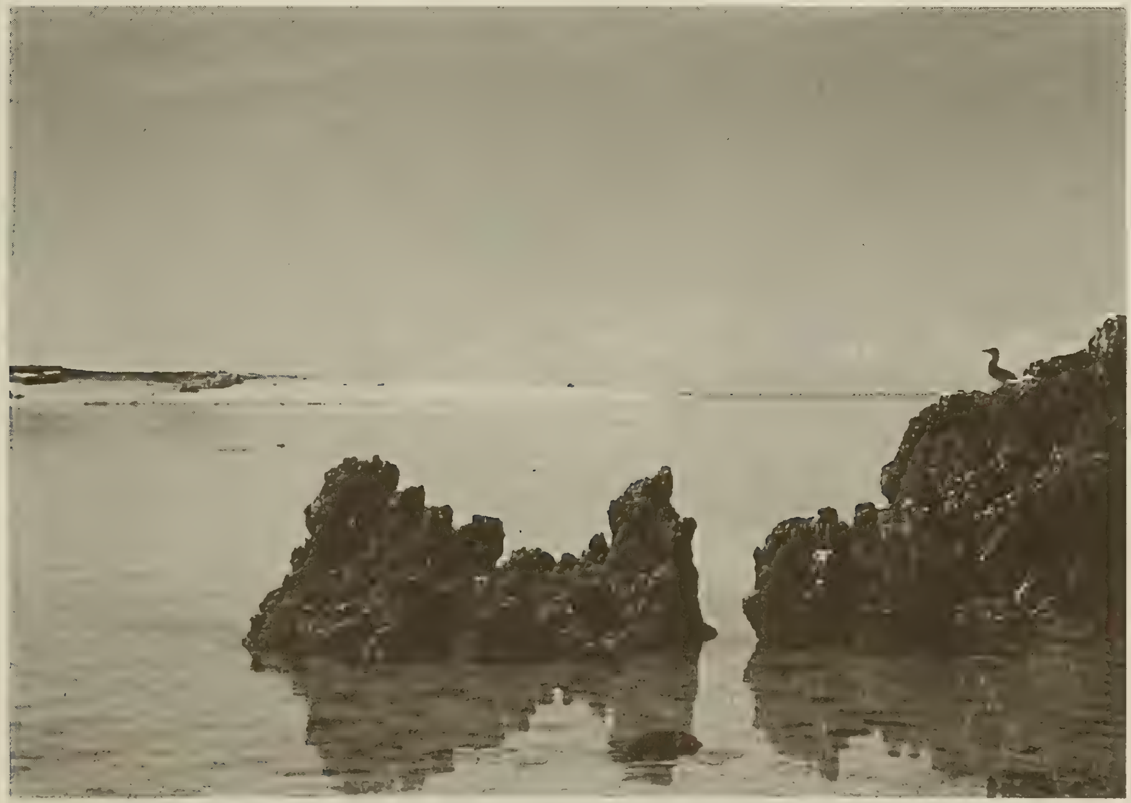

Plate 2. Pleistocene volcanic exposure in the Bramble Cay lagoon.

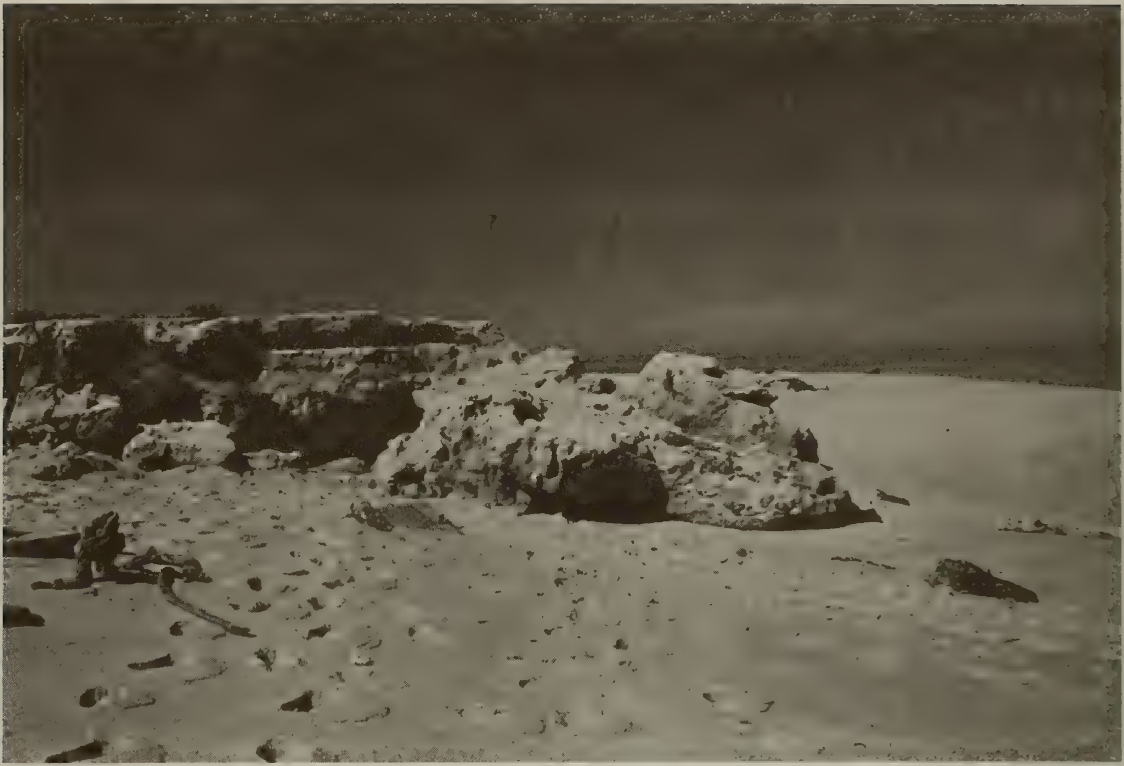

Plate 3. Phosphatic rock exposure (to 1.9 m above HTM) on the SE shore.

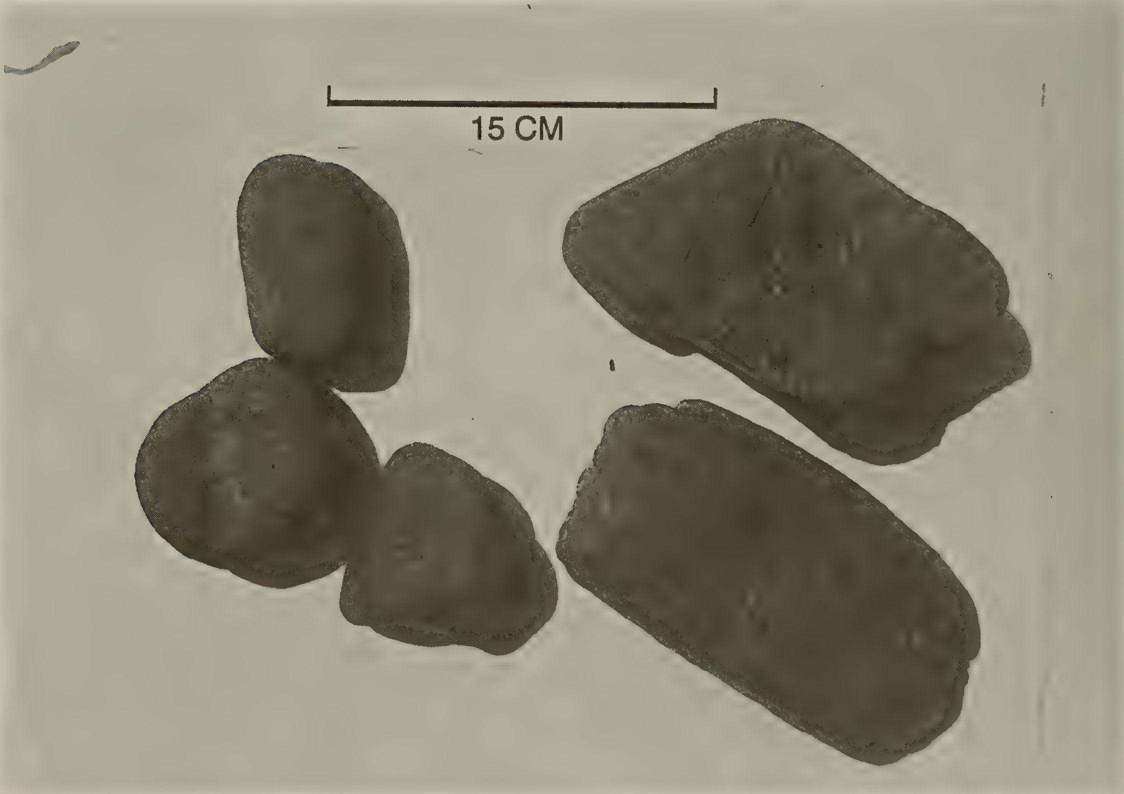

Plate 4. Coal collected from wave cut sand exposures, Bramble Cay.

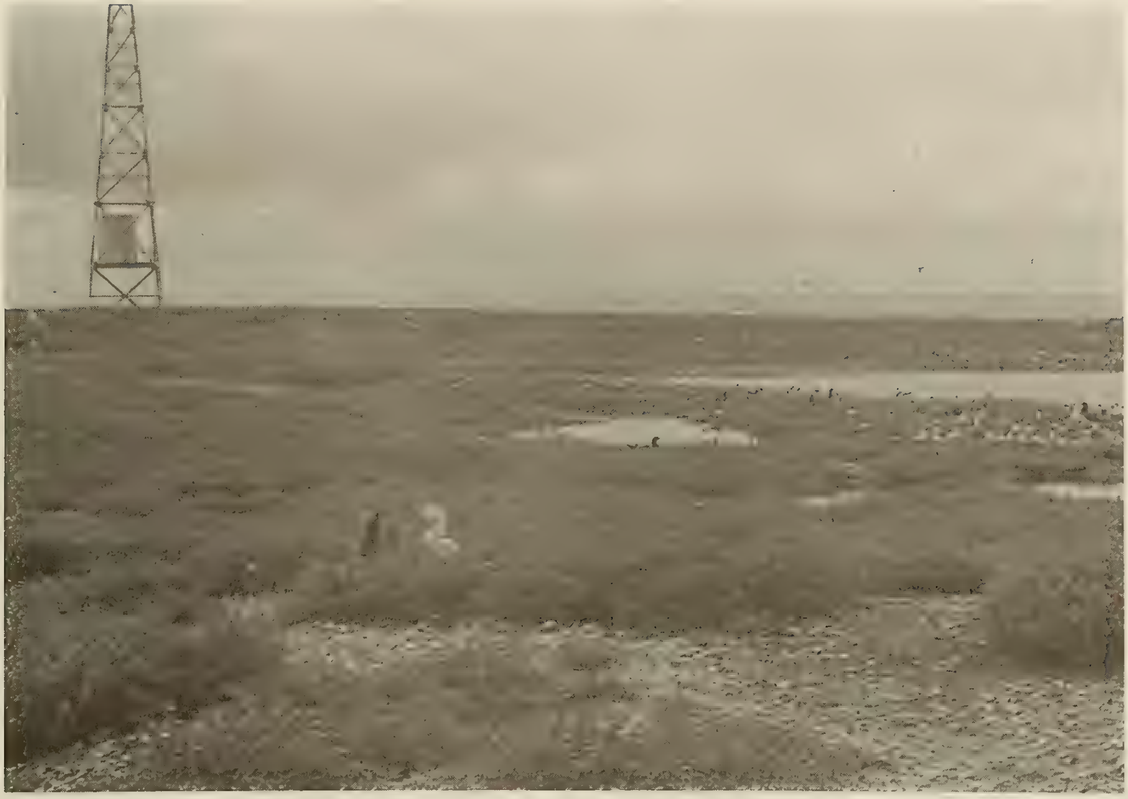

Plate 5. Inland of Bramble Cay, showing Boobies nesting on higher ground in the foreground, crested terns nesting on lower ground adjacent to water pools, and the lighthouse.

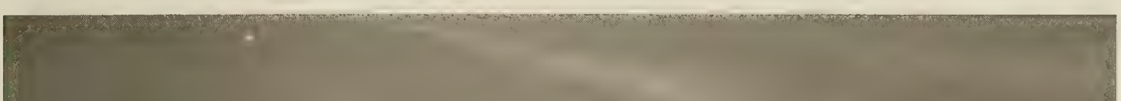

Plate 6. Remains of the 1958 lighthouse.

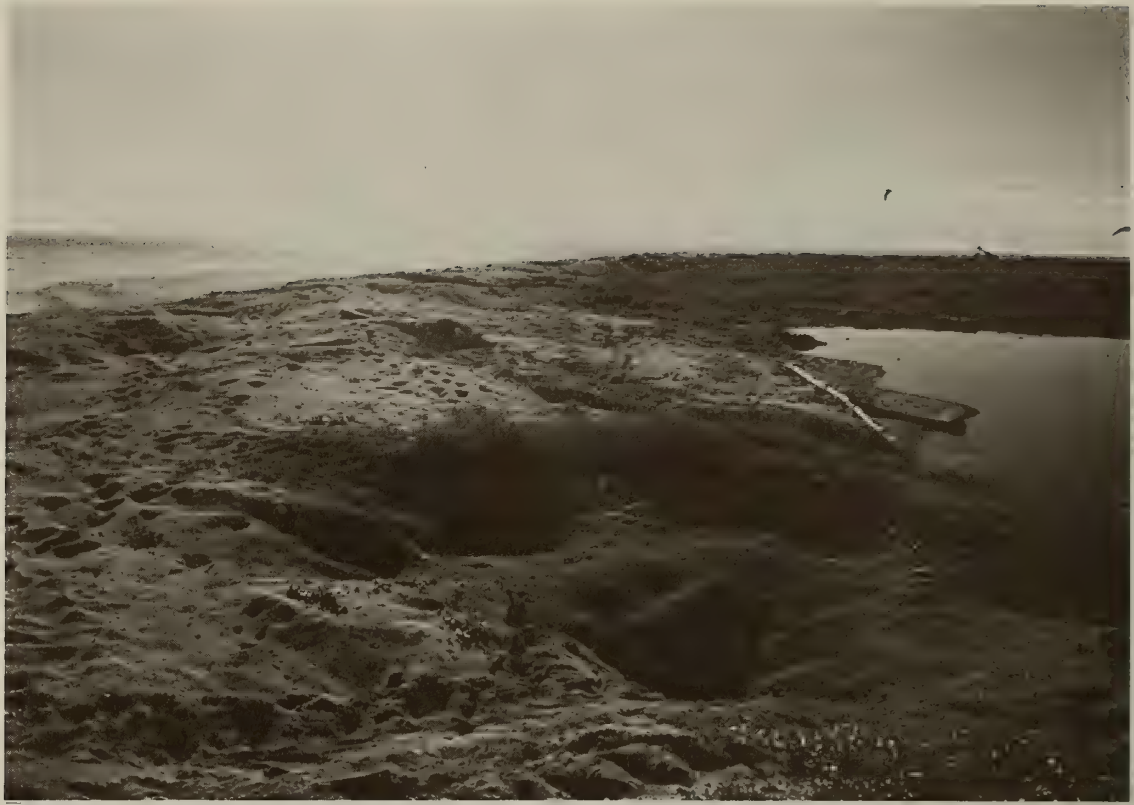

Plate 7. Illustration of how turtle nest craters limit the vegetated area, this from the southern margin of the cay.

Plate 8. Eroded south shore of Bramble Cay, February 1995.

Table 1. Major element analysis of rock and soil from Bramble Cay.

		Phosphatic rock	Soil surface
Fe	%	0.04	0.04
Mg	%	1.10	0.34
Al	%	0.05	0.03
Ca	%	32.8	18.6
Cu	ppm	3	34
P	%	4.77	14.8
Na	%	0.72	0.24

Table 2. Chronological record of human visitors to Bramble Cay

DATE	VESSEL	VISITORS	NOTES	REFERENCES
Ongoing		Darnley Islanders	collect turtles, birds, eggs	Johannes & MacFarlane, 1991
1791 (25 Aug)	*Pandora*	Capt. E. Edwards	passed island	Haddon, 1935
1845 (April)	*Midge*	Blackwood Jukes	noted igneous rock in center of coral ring	Sweatman 1977
1845 (6-7 May)	*Fly*	Blackwood Jukes	on way to N.G. coast	Jukes 1847
1845 28-29 May	*Fly & Prince George*	Jukes Blackwood	while surveying N.G. coast	Logan Jack, 1921
1846 4-9 April	*Bramble*	Yule Sweatman	collected eggs, spinach 5 turtle taken	Sweatman 1977
1846 3-8 June	*Bramble*	Yule Sweatman	collected eggs	Sweatman 1977
1849 (28-29 Sept)	*Bramble* *Rattlesnake*	Yule	en route N.G. to Cp York to get supplies	Logan Jack, 1921 Huxley, 1935
1849 (16-19 Dec)	*Rattlesnake*	Capt. Stanley MacGillivray	collected turtle/ bird eggs noted many boobies	MacGillivray, 1852 Huxley, 1935
1873 (?April)	*Basilisk*	Rev. A.W. Murray	trading paddlesteamer	
1875	*Chevert*	G. Masters J. Brazier	Ornithology Shells, molluscs	Masters, 1875 Brazier, 1876, 1877a,b
1889 (24.3)	*Janbaas*		shipwrecked on cay	Loney, 1982
1889 (July)	*Kenilworth*		shipwrecked NW of cay	Loney, 1982
1889 (20.8)	*Windhover*		wrecked on cay carrying coal	Loney, 1982
1889 (Sept.)	*Rosie Welt*		shipwrecked near cay	Loney, 1982
1915 (28.8-13.9)	*Mutlah*		ran aground, unloaded thousands of tons of coal	Done 1987 J. Foley. pers. comm.
1911 (27 July)	?.	W. MacGillivray	Ornithology	MacGillivray 1914
1917 (Sept)	*Herald*	Rev. J J E Done	used some coal for fuel took turtle, eggs	Done 1987

Table 2. Continued.

DATE	VESSEL	VISITORS	NOTES	REFERENCES
1924 (Sept)	?	C. Hedley	collection of corals water quality	Nathan, 1924 Hedley, 1925
		F. Jardine	geomorphology	Jardine, 1928
1927-1934		M Murray	visits with Darnley Islanders	Johannes & MacFarlane, 1991
1950's ongoing	*Trader Horn* others	B. Whittaker	mackeral fishing	Anon, 1955
1954-1987	AMSA vessels		acteylene replacement lighthouse maintenance	AMSA records
1975 (7 Nov) 1976 (3-5/1)	Dinghy from York Island	Applied Ecology	Turtle nesting count	Kowarsky, 1978
1978-79 Oct-March	(resident)	Applied Ecology	Turtle research, Island mapping	Onions, 1979 Parmenter 1980
1987 (Dec)	(dinghy)	C. J. Limpus		Limpus, et al., 1983
1988 (Dec)	(dinghy)	C. J. Limpus		Limpus, et al., 1983
1984	(dinghy)	C.J. Parmeter		Walker, 1988
1987 (4-6 Jan)	*M.V. Lumen*	T. A. Walker A.M.S.A.	Island survey LH conversion to solar	Walker, 1988
1988 (July)	*Western Venturer*	OK Tedi R.C. Babcock	Coral survey	Babcock 1988
1994 5-7 Feb	*R/V Lady Basten*	A.I.M.S.	Coral coring Island survey	Brunskill, in prep. This study
1995 17-19 Feb	*R/V Harry Messel*	A.I.M.S.	Coral coring Island survey	Brunskill, in prep. This study

Table 3. Properties of water pooled on Bramble Cay.

Location	Time	Temperature °C	Salinity	Conductivity
1	1440	39.7	0.8	9.0
2	1500	42.2	2.8	4.7

Table 4. Drift dissemenules on Bramble Cay

Species	1994	1995
Mangrove		
Avicennia marina	12	128
Bruguiera existata	10	75
Bruguiera gymnorrhiza	10	50
Bruguiera parviflora	1	1
Ceriops australis	4	11
Ceriops decandra	3	16
Ceriops tagal	3	7
Cynometra iripa		2
Heritiera littoralis	33	660
Nypa fruticans	302	374
Rhizophora apiculata	81	163
Rhizophora mucronata		45
Rhizophora stylosa	27	87
Xylocarpus granatum		845
Xylocarpus moluccensis		123
Xylocarpus sp.	27	
SUB-TOTAL	513	2587
Non-mangrove		
Aleurites moluccana	2	14
Barringtonia asiatica	3	15
Barringtonia racemosa		1
Caesalpina bonduc	1	6
Calophyllum inophyllum	1	
Canavalia sp.	2	
Cerbera manghas		17
Cerbera odollam	12	11
Cocos nucifera	12	10
Dalbergia canadensis	2	
Dendrodium sp.	1	
Entada phaseolus	3	16
Euphorbiaceae	30	102
Guettarda speciosa		7
Inocarpus fagifer	25	0
Ipomoea sp.		2
Leguminosae	32	333
Mangifera indica	1	5
Pandanus sp.	4	14
Pongomia pinnata	1	55
Pterocarpus sp.	2	
Terminalia sp.		11
SUB-TOTAL	134	619
TOTAL	**647**	**3206**

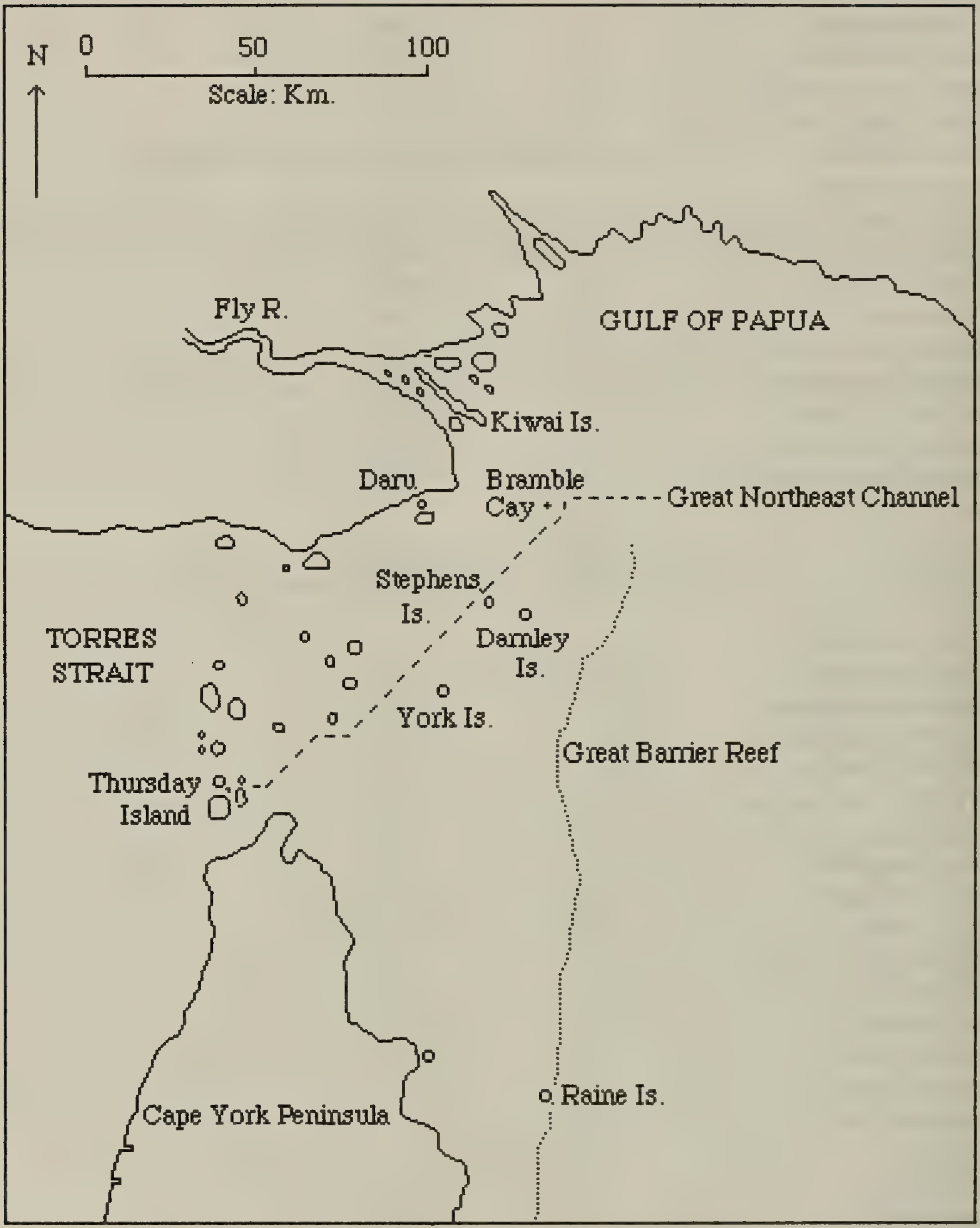

Figure 1. Location of Bramble Cay in the Torres Strait.

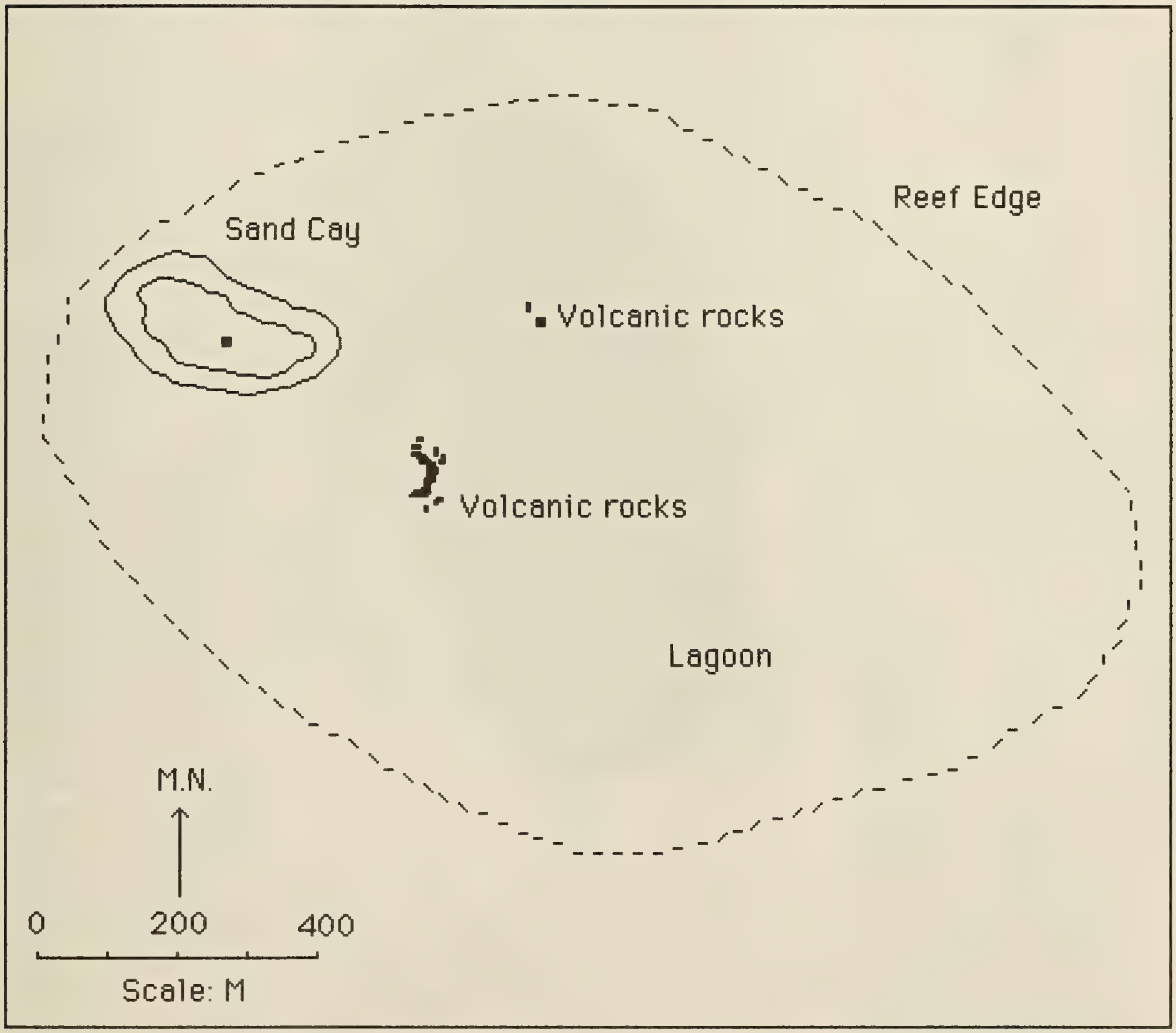

Figure 2. Map of the Bramble Cay Lagoon

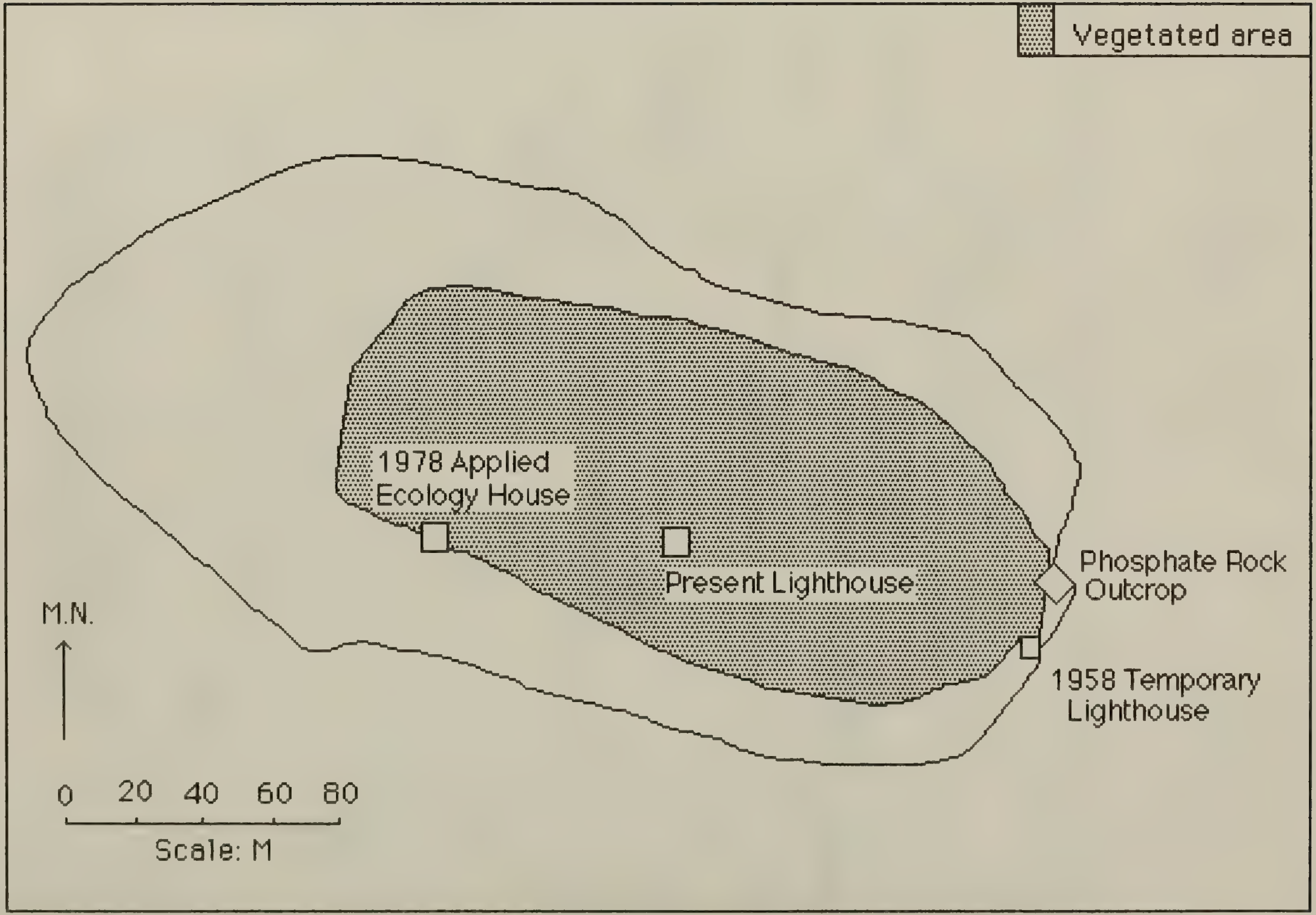

Figure 3. Map of Bramble Cay in February 1995, showing man made structures

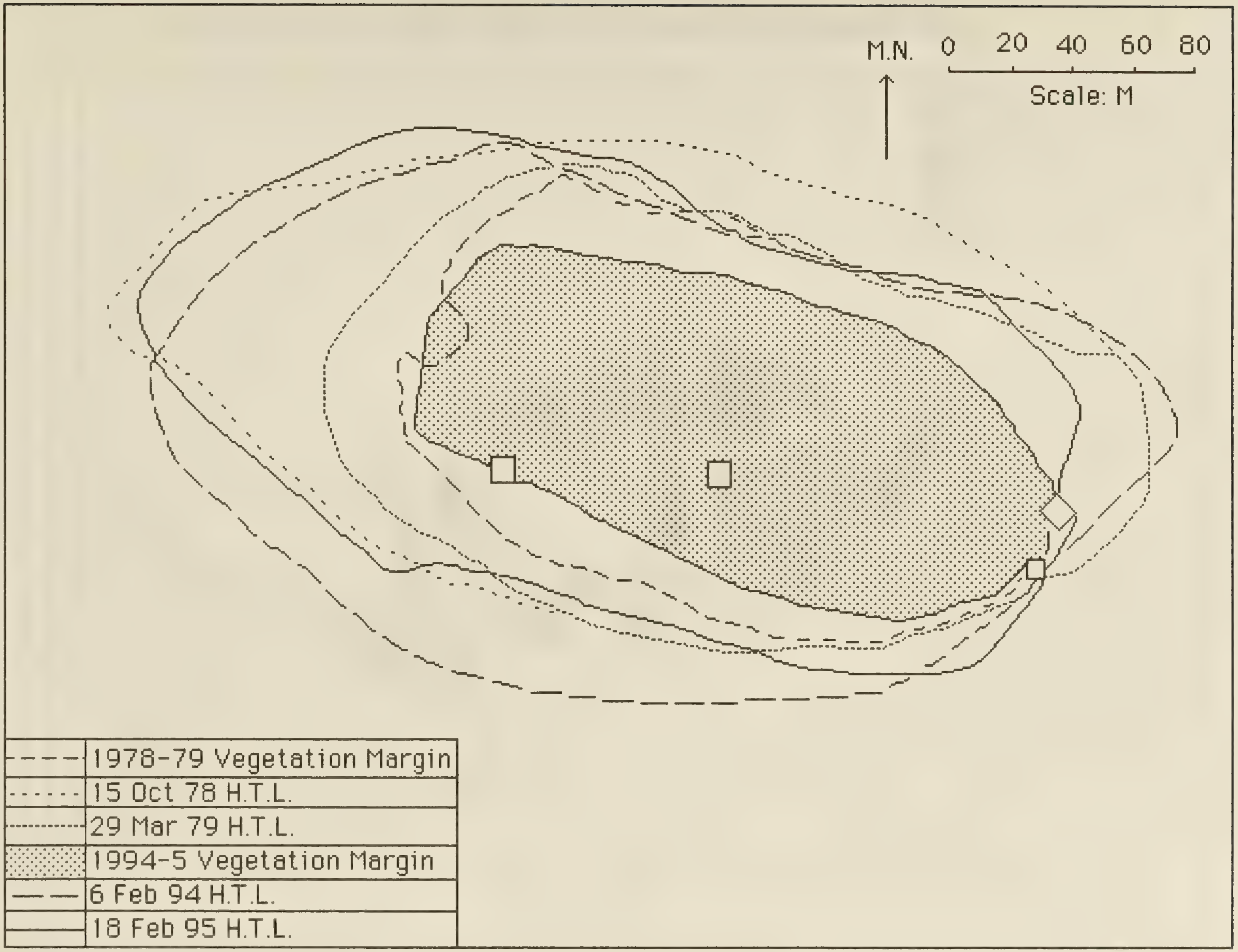

Figure 4. Change in shape of Bramble Cay 1978-1995

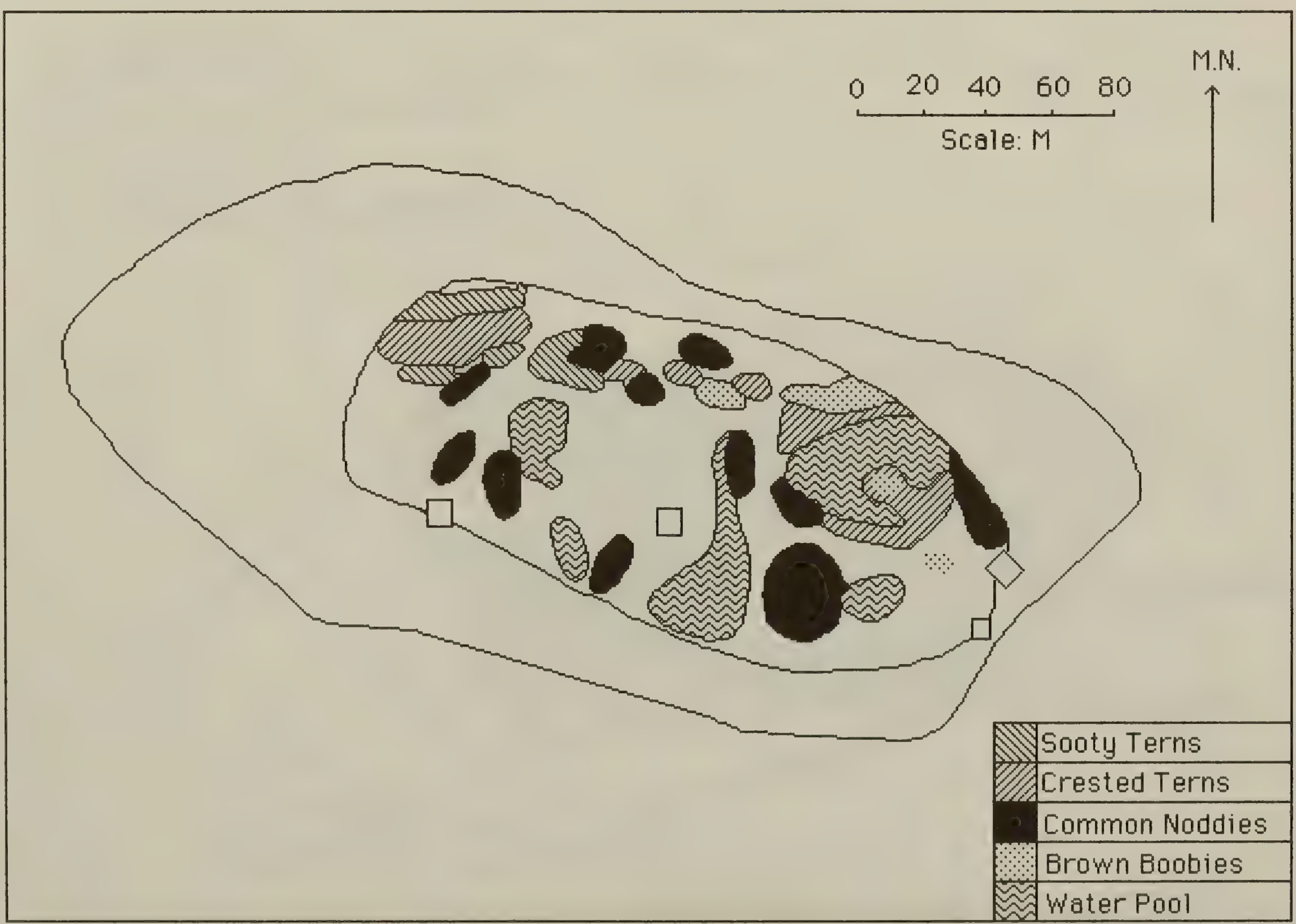

Figure 5. Bird nesting colonies on Bramble Cay, February 1995

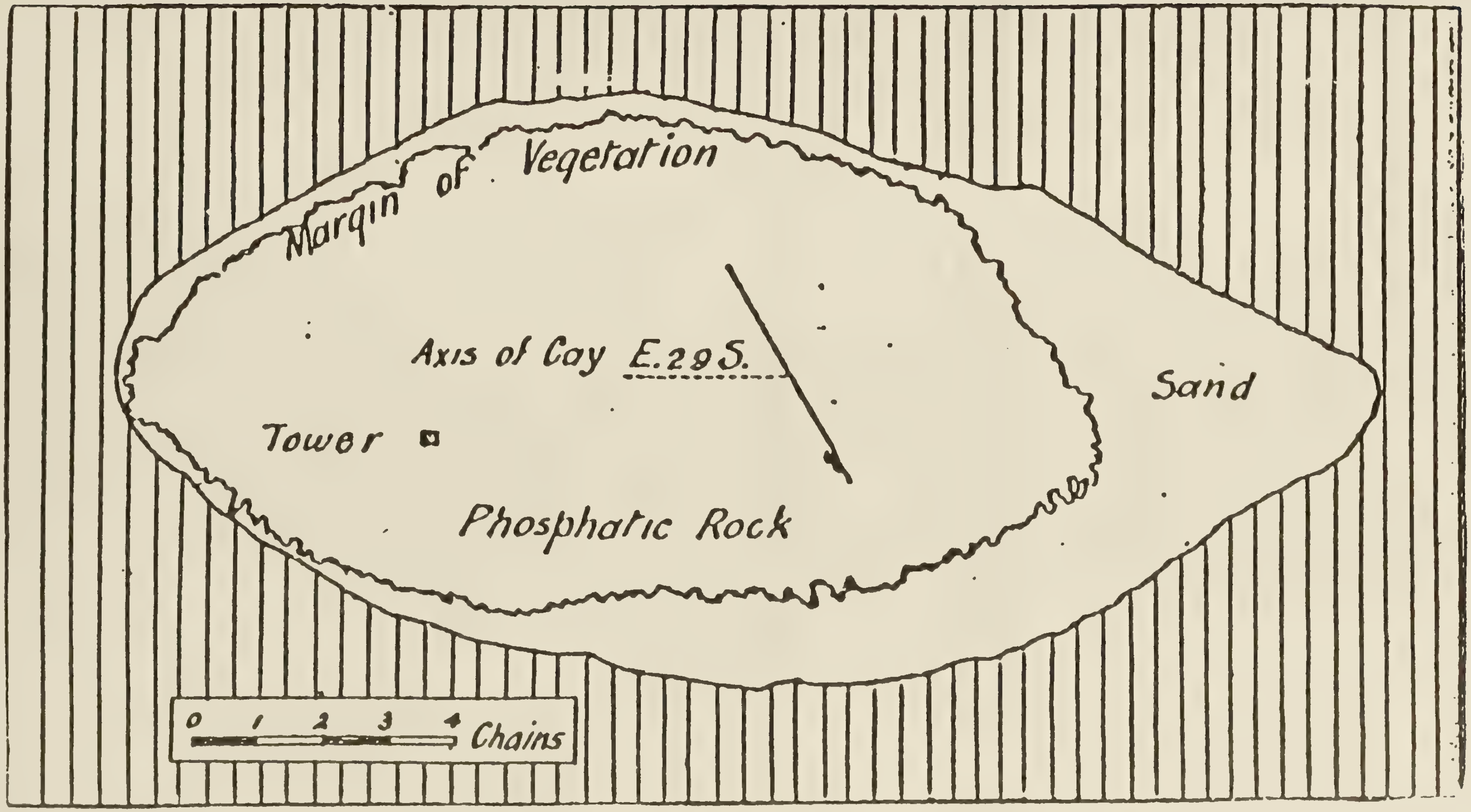

Figure 6. Map of Bramble Cay in September 1924 from Jardine (1928).
Scale: 4 chains = 80.48 m.

ATOLL RESEARCH BULLETIN

NO. 456

BIOTIC CHANGES IN THE REEF COMPLEX OF SAN ANDRÉS ISLAND (SOUTHEASTERN CARIBBEAN SEA, COLUMBIA) OCCURRING OVER NEARLY THREE DECADES

BY

S. ZEA, J. GEISTER, J. GARZÓN-FERREIRA AND J.M. DÍAZ

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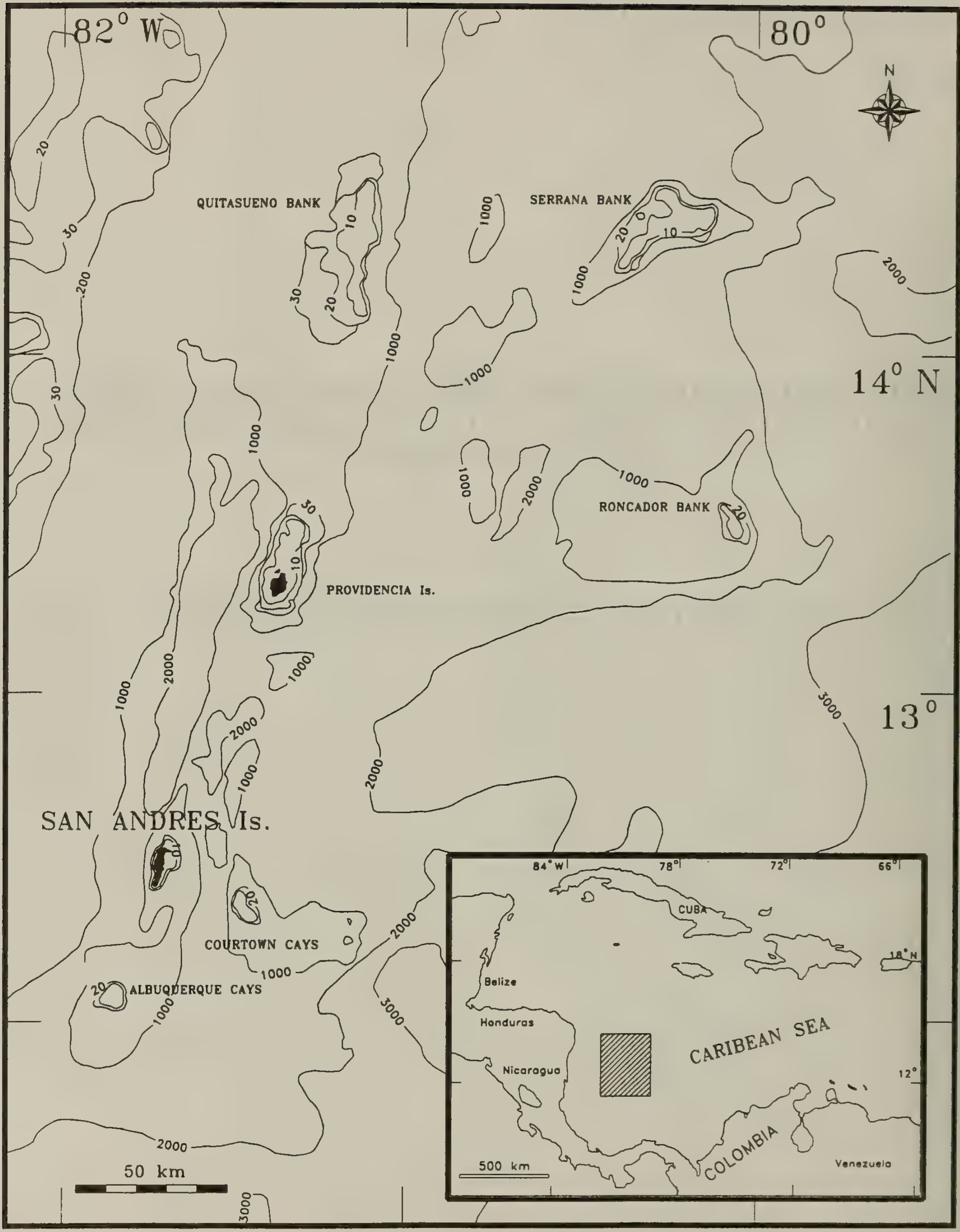

Figure 1. Map of the Southwestern Caribbean with the location of San Andrés Island and other nearby Colombian insular territories. Contour lines are isobaths (in meters).

BIOTIC CHANGES IN THE REEF COMPLEX OF SAN ANDRES ISLAND (SOUTHWESTERN CARIBBEAN SEA, COLOMBIA) OCCURRING OVER NEARLY THREE DECADES

BY

SVEN ZEA [1,2], JÖRN GEISTER[3], JAIME GARZON-FERREIRA[1]
AND JUAN M. DIAZ[1]

ABSTRACT

San Andrés Island (SW Caribbean, Colombia), an uplifted oceanic atoll of Miocene origin, consists of a well-developed coral and carbonate bank-barrier reef complex. From a former cotton and coconut economy in 1953, it became a major trade and tourist center currently having a population of more than 50,000 inhabitants in a land area of just 25 km^2 . Human activities directly affecting the marine environment have included dredge and fill operations, shipwrecks and groundings, disposal of urban waste, thermal pollution, over-fishing, construction along the shoreline, and diving, boating and beach-going activities. From qualitative observations carried out from 1968 to 1979, and quali- and quantitative resurveys made in 1992 to 1996, major biotic changes became evident in the upper insular platform (0-25 m in depth). These were: a detectable decline in live coral cover (to an overall mean of 30 % of hard substrata in 1992), extensive recent coral mortality (overall mean in 1992 of 52% of total live + dead coral cover), almost total disappearance of the long-spined urchin *Diadema antillarum* and the sea-fan *Gorgonia ventalina*, proliferation of algae (to about 60-70% cover of the overall reef hard substrata in 1992), and an almost total absence of commercial reef organisms, including both carnivores and herbivores. With exceptions due to localized solid and sewage disposal, coastal construction and ship groundings, coral death followed a spatial pattern of increased values in lagoonal, enclosed environments and lower values in high energy zones and in deep reef areas. The higher coral death in shallow lagoonal areas was interpreted as being directly caused by a greater susceptibility of coral species making up the shallow reef frameworks (i.e., *Acropora*, *Porites*) to hurricane and storm damage and to diseases. Indirectly, it may have been caused by the effect of the prevalent regime in lagoonal areas of higher illumination (allowing greater algal growth after the die-off of *Diadema*), low turbulence and limited water flushing (causing higher susceptibility to bleaching and diseases, and lower rates of natural and artificial lesion regeneration), and by a higher incidence of lethal or chronic effects of anthropogenic activities. San Andrés constitutes a typical example of the widespread phenomenon of over-development and poor planning of small islands. Its growing recreational tourism, which is based mostly on attractive and "healthy" seascapes, will soon be seriously threatened.

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Manuscript received 8 April 1997; revised 24 July 1998

INTRODUCTION

As coral reefs commonly fringe tropical islands and coasts, this resource is increasingly exploited for food through subsistence fisheries by the growing local populations. In addition, coral reefs represent valuable resources of recreational, scenic and cultural importance and thus also become a prime focal point for the local and regional tourist industries. Hence, reef protection and conservation has become an increasingly applied discipline oriented towards the preservation of the economic bases of traditional island communities.

A number of coral reefs throughout the tropical oceans have been investigated during the past decades and alarming signs of degradation have been recorded (see Ginsburg & Glynn, 1994). But the most stirring observation resides in the fact that vast areas of remote reefs have never been studied at all. Thus, an accurate global evaluation of the present world-wide reef decline is not possible, not even within the Caribbean Sea where degradation is especially alarming on a regional scale (see Ginsburg & Glynn, 1994; Hughes, 1994; Shulman & Robertson, 1996).

The Archipelago of San Andrés and Providencia (southwestern Caribbean Sea) comprises a series of islands, atolls and banks, built as oceanic reefs capping steep seamounts, facing an effective windward fetch of about 2000 km which corresponds to the entire width of the Caribbean Sea (see Milliman, 1969; Geister 1973, 1975, 1977, 1992; Díaz et al., 1996; Geister & Díaz, 1996). The surface outcrops of San Andrés, the main island of the archipelago, correspond to a thickness of about 500 m of coral and lagoonal rocks of Miocene age (Geister, 1975). Thus, the geological record of San Andrés alone is proof for the long-term ability of the reef-building community to produce wave-resistant frame-works and to accumulate an extraordinary mass of limestone on top of a subsiding seamount. In spite of major periodic or aperiodic perturbations of the environment that occurred in the geological past (see Copper, 1994), this ability may be under renewed long-term threat in the future as a result of a foreseeable global climate change (see Wilkinson & Buddemeier, 1994). Even worse, however, the short-term survival of the San Andrés reefs is jeopardized, at present, by the acute anthropogenically driven deterioration of the environment. Similar to other Western Atlantic reefs, coral communities around San Andrés show manifest signs of stress and lethal damage. Preliminary observations indicate that these have to be attributed, at least in part, to both heavy over-exploitation of the reef ecosystem by excessive fishing and to an ill-planned tourism development (Díaz et al., 1995). The fate of the already ailing fishing industry and the future tourism industry of San Andrés will depend greatly on a "healthy" condition of its reefs, accessible only for sustainable fishery and recreational activities such as beachgoing and diving.

The purpose of this paper is to document some of the biotic changes observed in the reef complex of San Andrés in the course of the last 28 years (1968-1996), to discuss their distributional patterns around the island, their temporal persistence and probable origin.

STUDY AREA

Location and history

San Andrés (12^0 29'N, 81^0 43'W) is part of an oceanic archipelago comprising two highstanding islands (San Andrés and Providencia) and a number of atolls and coral shoals that line the Lower Nicaraguan Rise for more than 500 km (Fig. 1). The island has a central topographic ridge reaching almost 100 m in height (Fig. 2). It comprises a land area of 25 km^2 and is inhabited by a fast growing population of more than 50,000 (I.E.S.A.P., 1990a) possibly reaching 80,000 today. San Andrés was first settled by English Puritans in 1631 and for almost 200 years it changed hands between Spanish and English rules. Although situated in the southwestern Caribbean Sea far away from the South American mainland and close to the Central American coast, the archipelago has belonged to the Republic of Colombia since 1822 (Parsons, 1964). Its economy developed from early cotton plantations into a coconut monoculture, the latter thriving at the turn of the century, accompanied by subsistence farming and fishing. In the brief time span of about 20 years, starting in 1953, a major tourist and trade center was formed (I.E.S.A.P., 1990b).

In spite of the limitations and the fragility of insular resources (McEachern & Towle, 1974) modern mass tourism was actively developed, which created an unprecedented need for manpower resulting in a sharp increase of the resident population. This demand also fostered investment into the housing and hotel infrastructure. Population pressure and resulting construction activities in turn led to a disorderly urban development, which appears to be one of the principal reasons for the growing environmental problems in the surrounding sea. Hitherto, the anthropogenic deterioration of the environment has been studied in some detail only for the mangroves (Contreras, 1982) and for the coral reefs (Díaz et al., 1995).

Human activities affecting the marine environment

Human activities that have directly affected the local marine environments in the last three decades are the following:

1. Dredge and fill operations carried out at the east coast near the capital of North End from about 1966 to 1970 by the VAM Suramericana S.A. They deepened and widened the harbor, enlarged the wharf, and gained new land for housing the rapidly growing population. These operations destroyed large seagrass flats and nearshore mangrove communities as well as island swamp areas that were filled by sand. Their effect on nearby patch reefs in the eastern lagoon has never been evaluated.
2. Dynamiting of coral shoals near "Entrance" in summer 1970 to permit a free passage to the harbor by vessels of major draught.
3. Ship wrecks and groundings both on the barrier reef and lagoonal reefs.
4. Disposal of urban waste (both sewage and solid) from the leeward coastal cliff directly into the sea.
5. Thermal pollution and pollution by hydrocarbons due to the inadequate cooling system of the local electric power plant destroyed much of the nearshore mangrove

communities along the east coast. The eventual impact on nearshore coral patches and on the seagrass communities has never been studied.

6. Overfishing of both carnivore and herbivore species to meet the needs of a growing resident and tourist population.
7. Construction of hotels along the shoreline or even in the sea along the north coast.
8. Diving, boating and beachgoing activities due to tourism.

Each of these disturbances directly impact only portions of the various marine environments. However, because of the interdependence of the coral reef, mangrove and seagrass ecosystems (Ogden & Gladfelter, 1983), the indirect effects may have been even larger, but not always well understood.

Recent reef complex

The present bank-barrier reef complex on the insular shelf consists of a barrier/fringing reef sheltering a windward lagoon, up to 3 km wide, with patch reefs and minor lagoonal fringing reefs. A 500 m to more than 1000 m wide rocky Fore-Reef Terrace slopes gently (3-8°) from about 8 m in depth to the drop-off of the island slope at around 20 m in depth or more. There is only one short leeward segment of the barrier reef protecting the northern lagoon to the west. Off the western or leeward island coast no structural coral reefs have developed. The insular shelf on this part of the coast is formed by two submarine terraces with marginal escarpments at depths of about 4 m and 20 m. The leeward 20 m terrace represents a continuation of the windward fore-reef terrace which was formed by truncation during a Pleistocene low sea-level stand. It is notable for its dense coral carpets and extensive sediment cover. The Holocene 4 m terrace forms rocky flats showing only very sparse coral cover with exception of its outer margins which are densely overgrown by corals (Fig. 2, 3).

Most reefs show rich coral growth with a clearly discernible zonational pattern (see Geister, 1975, 1977). The breaker zone of the windward barrier crest is dominated by luxuriant growth of the hydrocoral *Millepora* and the colonial zoanthid *Palythoa* with crustose coralline algae (*Porolithon* and others). *Acropora palmata* patches are common in the fore-reef from 4 m down to about 10 m in depth, and in the shallow water behind the reef crest. In localized shoals of particularly heavy surf, true algal ridge formations have developed in the northern part of the insular shelf.

Although no structural reefs grow along the leeward coast, dense coral carpets formed by branching and massive scleractinians with abundant octocorals cover the outer margin of the 20 m terrace between 15 and 20 m in depth. Shoreward from this carpet, between 15 to 8 m deep, there is a zone of varying width characterized by carbonate sand accumulation. The upper island slope below the leeward drop-off at about 20 m is covered by rich coral growth comparable to true fore-reef settings. More detailed descriptions of the geology, geomorphology and marine environment of San Andrés have been published elsewhere (Geister, 1975; Diaz et al., 1995, 1996).

METHODS

Initial observations were carried out between June 1968 and September 1970, in April and May 1973 (Geister, 1973, 1975), in May 1977 and in July 1979 (Geister, unpubl.). These were made almost exclusively by extensive snorkeling accompanied by a dug-out canoe. Almost the whole reef complex was covered in detail by this method from the shore down to the outer edge of the insular shelf. Main observations concerned geomorphology, species composition of reefs and ecological zonation. Observations were noted on board and numerous photographs were taken underwater.

After an interruption of observations for almost 13 years, renewed investigations were undertaken with qualitative and quantitative surveys in May and September 1992 (Garzón-Ferreira & Kielman, 1994; Diaz et al., 1995) followed by a short visit of the reefs in June 1993, a joint resurvey of several original sites in October 1994 and a last visit in 1996.

During the 1992 resurvey, SCUBA was used and observations were made at 48 stations (Fig. 2) each in a relatively homogenous reef zone, visually estimating the percent cover of: (1) major hard bottom components such as live scleractinian and milleporid corals, other invertebrates and algae; (2) live area of dominant coral species relative to total live coral cover; (3) total area of recently dead coral relative to total coral cover (live and dead); (4) dead surface area of each dominant coral species relative to its total cover (live and dead). During these surveys, the presence and the extent of coral diseases or other signs of coral stress, the unusual proliferation or absence of other organisms, and the presence of anthropogenic sources of impact were noted too.

Considerable recent coral death has occurred over the last 2 to 3 decades. For its gross estimation, only those tissue areas which can be expected to be alive in healthy colonies (exposed, non-cryptic sides of coral heads or plates; distal portions of coral branches) were taken into account. Coral skeleton remains not too grossly eroded or collapsed to permit distinction of original colony limits and growth form were also considered for estimation. For gorgonian octocorals, mortality rates were estimated from the percentage of dead skeletal remains relative to the total (live and dead) number of colonies present. The density of this total was also visually estimated. All these estimates can only produce approximate values due to differential colonization of species by epibionts and to different patterns of mortality and subsequent erosion. In addition, it must be taken into account that estimates of live and dead coral cover were each taken by a different observer, though on-board discussions among the diving party, generally, helped to minimize subjective mistakes. More objective observations of coral cover were made from chain transects laid on the sea bottom parallel to the coastline, three in each of 14 stations. The percent cover was calculated from the number of chain links overlying specimens of different taxa and types of substratum relative to the total number of links (600).

The 1994 and 1996 resurveys were carried out by swimming over several of the sites originally surveyed in 1968-73, noting gross changes in species composition and dominance, and the presence and extent of coral death. Coral species-morphs follow Geister (1975); *Montastraea annularis* was at that time not split into its three sibling species under discussion now (see Weil & Knowlton, 1994).

Cartography was based on maps published by Geister (1973), as well as on the following aerial photographs obtained from the "Instituto Geográfico Agustín Codazzi" (IGAC) at Bogotá: flights C-2123 (1984), C-2420 (1990) and C-2422 (1990). In addition, the British Admiralty Chart 1511 surveyed in 1834 was used as well as the nautical chart of the Colombian Navy COL-201 published in 1972.

RESULTS

Coral decline

Although percentages of live and dead coral cover were not recorded in 1968-73, field records and underwater photographs show clearly that the coral formations around San Andrés were in healthy condition at that time except for local damage recorded in the NE and N lagoons (see below) (Geister, 1975). During the 1992, 1994 and 1996 resurveys it became certain that live coral cover diminished considerably during the last 28 years due to intensive and widespread coral mortality in the reefs.

Present live coral cover

Visual estimates of live coral cover made in 1992 at 47 stations (50 data points) ranged from 0 % to 60 % of hard substrata with a mean of 26 % (Table 1). This indicates that on an average less than one third of the hard substrata of the San Andrés shelf is presently covered by live corals. Quantitative data obtained from chain transects at 14 stations gave similar values of mean live coral cover of the hard substrata (30 %, Table 1). Values of live coral cover equal to or surpassing 40% were found in the southern portion of the leeward 20 m terrace (Station 39), and at scattered stations in the windward barrier reef, at the outer edge of the fore-reef terrace and in parts of the lagoon (stations 8, 10 and 20) (Table 1, Fig. 3). As there are no quantitative data from previous years, we cannot directly estimate the decline in coral cover. Nevertheless, other evidence, such as photographs of sites revisited again and the omnipresence of great amounts of recently dead coral colonies are indicative of such a decline.

In 1992, low coral cover was observed in areas of the leeward terraces in the neighborhood of the raw sewage outlet and solid waste disposal area (Horn Landing, Station 44-45, airport runway, Stations 46-48), when compared to similar stations of the same facies in the SE sector of the island. However, coral species composition and relative cover did not vary much on average between the stations in the NW and SE, suggesting that the above pollution did not cause a noticeable coral species replacement.

Recently dead coral

High levels of recent coral mortality were recorded at San Andrés in 1992. Visual estimates of the proportion of dead coral at 47 stations showed an overall mean of 52%, ranging from 10 to 99% (Table 1). More than half of the stations had mortality values higher than 50%. The highest levels (>80%) were found in the lagoon, on the patch reefs dominated by one or two species of branching or foliose corals (*Acropora, Porites, Millepora*), while the lowest mortality values were estimated in the spur and groove system of the barrier reef where the dominant species was *Millepora complanata* (Table 1, Fig. 4). When comparing these visual estimations to those obtained from chain transects (Table 1), it is noticeable that some are similar (Stations 8, 25 and 28), but the majority show a difference of 20% or more in the chain estimations. This is probably due to a closer and more detailed exploration of the reef substrata during the chain samplings, incorporating dead lateral portions of coral heads which were not easily seen in the visual estimations made when swimming at the surface, 1-2 or more meters above the substratum.

Coral species affected

During the 1992 San Andrés survey it was found that 19 coral species were affected by recent mortality (Table 2). Fourteen of these reached per-station mortality levels of 50% and more. *Acropora cervicornis* and *A. palmata, Agaricia agaricites, Eusmilia fastigiata, Millepora complanata, Montastraea annularis, Porites furcata* and *Siderastrea* showed mortality levels of 50% and more. These eight species had also the highest values of overall mean mortality (>25%) and relative frequency of mortality (stations with mortality over stations found) (>55%), with exception of *A. agaricites* and *P. furcata* which showed frequency values of only 24 and 41% respectively. On the other hand, *Diploria strigosa* and *D. labyrinthiformis* also had high mortality frequencies (58-60%). Only four species reached mean mortality levels of more than 50%: *A. cervicornis, A. palmata, E. fastigiata* and *Colpophyllia natans*. The most common coral was *A. cervicornis* which formed thickets in 1968-1970 at several sites within the lagoonal area (Geister, 1975)(Fig. 5a); these thickets were partly necrose, covered by filamentous algae and occupied by pomacentrid fish in 1977 (Fig. 5b). By 1979 this condition worsened considerably, so that more than half of these thickets were dead (Fig. 5c). During the 1992 to 1994 re-surveys, no living specimens of *Acropora cervicornis* (only dead fragments) of this species were seen at this site (Fig. 5d). Only a few small and isolated colonies of *A. cervicornis* were observed alive in deeper reefs (10-20 m). So it is possible to assert that less than 1% of the populations of this species survive at present.

Two of the most important species in shallow reef frameworks at San Andrés, *A. palmata* and *M. complanata*, showed very high mortalities in the lagoon and in the back of the barrier reef, as compared to the deeper inner fore-reef terrace (6 to 8 m) in front of the windward barrier where mortality levels were much lower (Table 1). Mortality of *A. palmata* was especially impressive in the shallow patch reefs of the northern lagoonal basin that were once dominated by flourishing stands of this species (see Geister, 1975: pl. 4 b+c). In 1993-6 the *A. palmata* in these reefs were mostly in their once-living positions, but were completely dead with the exception of a few younger colonies; only in one single flourishing coral patch, about 10 m in diameter, *A. palmata* seemed to be in vigorous expansion.

Another important branching species, *Porites furcata,* which dominated many of the shallow, protected reefs of the eastern lagoon shelf in 1970, was found almost totally dead in several of those patches adjacent to urban areas in 1992 (Table 1). However, some patches were already dead by 1970, and a few others retained healthy populations by 1992 (Fig. 6) and still by 1996.

Increase in algal cover and algal biomass

In 1968-70 the algal cover in the San Andrés reefs was very low as compared to the present values. Though no counts were made at that time, it can be shown by underwater photographs of sites resurveyed in 1994 that the reef became heavily overgrown by different species of macroalgae, even at sites where formerly no presence of algae was noticeable.

Frondose algae were prolific at many sites in 1992, 1994 and 1996, especially in areas protected from direct wave energy where they partially covered live coral colonies. Brown algae (Dictyotaceae, *Lobophora variegata* and *Stypopodium zonale*) were especially abundant, followed by the green calcareous algae *Halimeda* spp. (Figure 7). The proliferation of *Halimeda* in certain localized reef areas was quite impressive. Due to the fast growth rate of their thalli (see Hudson, 1995), these algae were able to outgrow and to overgrow both massive (*Montastraea*) and branching (*Acropora*) coral tissues which were ultimately killed, probably by overshadowing and suffocation. The coral tissue under the recently encroaching *Halimeda* was pale to white due to expulsion of zooxanthellae but was still alive, whereas it was already absent on the flanks which were overgrown earlier. The parts of a colony still emergent from the algal cover retained their original color and had a healthy appearance. In 1992 to 1996 the brown alga *Dictyota* and related species formed almost coherent carpets on the dead hard substratum of most reefs. These were practically devoid of algae in 1968-70.

The per-station algal cover in Table 1 indicate that algae, including crustose, turf and frondose forms by 1992 were a dominant group within the coral reef biota of San Andrés: In 85% of the stations, algae covered more than 50% of the hard substrata, whereas in the remaining stations they reached values ranging from 35 to 50%. Only in a few stations did live coral cover on hard substrata exceeded that of algae. In 10 stations algae had cover values greater than 80%, reaching up to 95%. With the exception of stations located on the shallow leeward 4m terrace, such high values corresponded to sites of considerable recent coral mortality. On an average, algal cover was near 70% (25-26% of frondose algae) in 1992. With a few exceptions algal cover values obtained from chain transects were similar to those estimated visually, the latter ranging from 29 to 90%, with an overall mean of 62% (Table 1).

Mortality of gorgonian octocorals

During the earliest surveys, the sea fan *Gorgonia ventalina* was a conspicuous and frequent species of San Andrés reef environments that were moderately exposed to swell and waves. It was observed commonly in shallow waters down to about 20 m in depth (Geister, 1975) and was especially conspicuous in shallow seaward fore-reef settings such as the barrier fore-reef slope between 3 and 8 m and the inner and middle fore-reef terraces between 8 and 15 m. In these areas, often largely devoid of scleractinians, the sea fans together with sea whips (plexaurids) formed lush "octocoral gardens" on hard bottom. *Gorgonia* was equally abundant in lagoonal patch reefs (see Geister, 1975: Pls. 3 and 4). However, in 1992, 1994 and 1996 there were very few live colonies of sea fans remaining, mostly young specimens. But numerous dead axial skeletons were seen, still attached to the substratum. Also partly dead colonies were conspicuous. The dead skeletons were overgrown by algae. Per-site mortality was estimated in 1992 to be from 60 to 100%, with a mean of 91.4% (Table 2). In addition, low mortality levels of several species of other gorgonians was detected. These were found in the dense octocoral stands on the leeward 4 m terrace (Stations 41, 43, 46 and 47) where 5% of the upright branches were observed dead at the northernmost station (Station 41) and 20% at the southernmost station (Station 47).

Mortality of the long-spined sea urchin *Diadema antillarum*

This urchin was formerly very abundant in the San Andrés reef complex as witnessed during visits between 1968 and 1979, being especially frequent in the shallow back-reef areas, such as the hard bottom of the boat channel of the seaward fringing reef south of Sound Bay and in the marginal areas of lagoonal patch reefs. *Diadema* was also ubiquitous among the coral communities along the 4 m terrace and the adjacent coastal cliff of the leeward coast.

In 1973 and 1975, *Diadema* clusters of up to 10 specimens and more were commonly noted on sandy bottoms of the shallow lagoonal terrance between East Reef and in the nearshore seagrass flats near Dry Shoal and Long Shoal. Here *Diadema* was especially conspicuous and easily recognizable as dark patches in shallow water. This aspect had changed radically when the reefs were revisited in 1992, i.e., 9 years after the Caribbean-wide 1983-84 die-off of the *Diadema* population (Lessios et al., 1984). Unfortunately, there are no recorded observations that might document the timing and impact of this event on the San Andrés reefs (Geister, 1992).

By 1992, only a few isolated specimens of *Diadema* were observed in the *A. palmata-Diploria-Millepora* zone of shallow reefs in the northern lagoon. *Diadema* also occurred rarely in occasional clusters of 3-4 specimens on coral patches behind the barrier reef. In June 1993, this situation was basically unchanged, but by October 1994 and October 1996, it seemed to have improved somewhat. But the *Diadema* population did nowhere attain the levels present before the die-off. Occasional *Diadema* were spotted in most reef habitats of the barrier, fringing and patch reefs. No *Diadema* clusters were seen in pure lagoonal sand areas and in seagrass habitats as observed before the die-off. The sea urchin was also still very rare in 1994 within the shallow coral associations of the leeward coast.

Reduction in populations of commercial organisms

We did not carry out population censuses of commercially important reef organisms at San Andrés. However, it was noted during the 1992 and 1994 surveys that certain of these species decreased in number to such an extent since the 1968-70 survey that today their exploitation is no longer economic or had to be abandoned because of the quasi-absence of the target species.

The queen conch *Strombus gigas* has been a popular food resource on the island and provides a number of typical island dishes. Traditionaly it was taken from San Andrés and also brought in numbers from the neighboring atolls of Courtown Cays and Albuquerque Cays. In 1968-70, the queen conch was still picked up regularly in the lagoon of San Andrés by spearfishermen . There were also a few natives who made their living by collecting conchs free-diving from small dug-out canoes in the northern lagoon. The catch was sold to the local population, and generally, a half-day's collecting trip was sufficient for a fisherman's subsistence. Therefore, it was most surprising that during the 1992-1996 surveys not a single living specimen even of a juvenile *Strombus gigas* was seen either in the northern or eastern lagoons, in spite of several days spent in the water by four experienced reef scientists.

Once, the spiny lobster *Panulirus* argus. was commonly collected by local spearfishermen, though already by 1968-70 it was less abundant than in the nearby atolls and in the reefs around Providencia Island. In 1992, 1994 and 1996 specimens were rarely observed, all of them of minor size. High demand by the local hotel industry resulting in overfishing is certainly one of the main reasons that lead to the decline of this valuable resource.

Large commercial fishes like snappers (*Lutjanus* spp.), groupers (*Mycteroperca* spp., *Epinephelus* spp.), grunts (*Haemulon* spp.), queen triggerfish (*Balistes vetula*), hogfish (*Lachnolaimus maximus*) and the great barracuda *(Sphyraena barracuda*) are rare to almost absent in San Andrés reefs. In 1968-70, all these species were caught by subsistence fishery and by spear-fishermen who also sold to the local hotels. By in 1970 a considerable amount of fish had to be imported from the Courtown Cays, Albuquerque Cays, and from Providencia to satisfy the needs of the local tourist industry. With increasing fishing pressure, the stocks in high-quality fish diminished drastically in the San Andrés reefs and also in those of the nearby cays. Hence, in recent years formerly despised non-traditional, lower-quality fishes, such as parrotfishes (*Scarus* spp., *Sparisoma* spp.), angelfishes (*Pomacanthidae*) and surgeonfishes (*Acanthurus* spp.), became also a major target for the local fishery. Since local reef fish became more and more scarce in the last 20 years, it has been noted in 1994 that more fish supplied to local restaurants are hemipelagic species such as the bonito (*Euthynnus alletteratus*), which are caught on off-shore banks over deeper water. Also deeper water species such as the silk snapper (*Lutjanus vivanus*) are caught on offshore banks. This species is commonly sold nowadays in local restaurants to clients as "red snapper" or "pargo rojo" (*Lutjanus jocu*) because the more favored species is practically absent from the local reefs.

Reef sharks (*Carcharhinus* spp.) were common in the 1968-70 period in the San Andrés barrier reef and especially frequent in the wave-swept Blowing Rocks area where they could be observed in packs of 4 to more than 10 individuals (Geister, 1975). During visits to the Blowing Rocks in 1993, 1994 and 1996 not a single shark was sighted. Shark meat is not used for human consumption by the population of San Andrés except for occasional production of shark liver oil. Occasional catches of sharks are sold to immigrants from the Colombian coast. The reasons for the quasi-absence of sharks are far from clear. In recent years the Blowing Rocks area - renowned for frequent shark encounters - as well as the barrier reef, were frequented more and more by divers and underwater photographers, which by their presence may have scared the sharks away. Also the main prey of reef sharks - large and medium-sized fishes - became rare in the shallow reef mainly due to overfishing by speargun.

Solid waste in the reefs

A wide marine area along the NW coast at the SW end of the airport runaway is largely littered by garbage which was discharged from trucks until the end of the eighties. It accumulated mainly on the 20 m terrace. Glass bottles, cans and other trash occupy many of the interspaces between coral heads on this deep terrace and many items have been incorporated into the reef framework. Up to 10 items per square meter were found at Station 45. On the shallow 4m terrace there was less dense but more diverse trash, also including wrecked vehicles, cardboard, ropes, nylon lines, cloth etc. In 1992, trash also occurred farther south. Some garbage was also found on the lagoonal terrace and in the lagoonal basin north of the island.

In recent years, this type of waste disposal has been abandoned and garbage is stored, burned and partly recycled on land. It may be expected that much of the garbage remaining in the sea will be overgrown by reef builders in the near future or covered by sediment. It is uncertain if any toxic substances impregnate sediment and skeletons, thus entering the food chain via grazing organisms.

Physical damage to the reef

Ship wrecks and groundings

Shipwrecks and groundings are a major problem to the San Andrés reefs. In 1994 and 1996 four major shipwrecks were visible alone in the barrier reef. Shipwrecks are especially destructive because corals and entire reef spurs are not only smashed during the stranding, but ship hulls tend to move shoreward subsequently bumping the sea floor with the rise and fall of waves and tides thus leaving a broad trail of death and destruction behind. This may reach from the higher fore-reef to the reef crest area. With time, wrecks tend to disintegrate during heavy storms, each piece being moved separately on the ground by the breaking waves. As a result, shattered ship planks, masts and motors commonly create a sphere of destruction where coral life is totally annihilated. Corrosion and abrasion of the iron stains the sediment, which is deposited in the lee of the wrecks.

In 1994, reef damage by wrecks was especially conspicuous at East Reef and Half-a-Reef, where entire thickets of *Acropora palmata* were fragmented and where *Millepora* reef spurs were entirely ripped off. At Half-a-Reef, several shipwrecks ocurred since 1970, the last being the "Anancy" from Kingston. The most beautiful spurs photographed in 1970 and figured in Geister (1975: pl.5-d) and Geister (1983: pl.27-2) were entirely destroyed by the pounding effect of these wrecks.

The effects of ship groundings that did not result in abandonement were observed in the ship channel that leads from Entrance to San Andrés Harbor. Here entering ships produce occasionally large cuts on the crests of shallow patch reefs. On the other hand tourist boat traffic inside the lagoon is presently so heavy that it poses a significant source of damage to local shallow reefs. Broken colonies of *P. furcata* in the very shallow fringing reefs may also have been caused by the effect of trampling tourists or storm waves. Several characteristic scars in the shallow seagrass beds along the northern shore, easily visible from air, were definitively produced by boat propellers.

Storm waves

Occasional storms may cause heavy damage to the reef framework, especially to branching scleractinians (Geister, 1992: 44-46). Fragmentation of colonies is especially apparent after hurricane passage and the most conspicuous impact is on *Acropora cervicornis*. Extensive rubble of dead fragmented *A. cervicornis* colonies was found all over the western end of Little Reef in 1968. The colonies had not recovered until 1994. Their destruction may have occurred during the passage of hurricane Hattie in 1961. Storm damage inflicted to *A. cervicornis* thickets at Half-a-Reef in about 1972 (Geister, 1975, Plate 6a-b) was still present in 1994. The *A. palmata* thickets from this same site were still flourishing in 1973, but in 1992 they were all fragmented and dead, probably smashed by waves of hurricane Joan which passed near San Andrés in 1988 (Geister, 1992). In 1992 and 1994 large coral colonies of the more robust *Diploria strigosa* and *Acropora palmata* also were seen overturned though still alive in parts of the northern lagoon and on the 4 m terrace of the west coast. There, piles of dead detached coral heads were also seen at the base of the shallow submarine cliff that connects the 4 m terrace to the inner margin of the 20 m terrace. Along the west coast, in places formerly rich in coral growth, many skeletons were broken and rocky surfaces polished due to abrasion by coral shingle. These sights were rather uncommon in 1968 to 1979 and must be attributed to physical drag and abrasion by hurricane "Joan".

DISCUSSION

Spatial patterns of coral death vs. causes

Considerable changes in the environment have been observed during the time lapse under consideration. Most dramatic is the high mortality of corals, the substantial decrease of commercial organisms, the almost total absence of the herbivore *Diadema antillarum*, and the proliferation of algae. Hughes (1994) identified a chain of causal agents on Jamaican coral reefs, ranging from overfishing, to the proliferation of *Diadema* due to lower predation and competition for algal resources, to extensive hurricane damage, to the demise of *Diadema* and the subsequent frondose algal bloom, which, together with further damage from coral bleaching, led to widespread coral mortality and recruitment inhibition, decreasing coral cover from 50% in the late 1970s to less than 5% today. Eutrophication has been pointed out as another agent causing algal bloom at Jamaica (Lapointe et al., 1997, Goreau et al., 1997).The same chain of events can be more or less traced at San Andrés and many other Caribbean reefs, with local or regional variations depending on factors such as occurrence of hurricanes, extent of overfishing, occurrence of widespread coral diseases, and induced anthropogenic damage from nautical activities, sewage discharge and excessive sedimentation, among others (cf. Ginsburg, 1994).

From the results presented herein, a spatial pattern emerges of greater coral death in lagoonal settings, and of lower coral death in high-energy zones (i.e., the barrier reef) and in the deep terraces and outer slope.

The high coral death in shallow, protected areas seems related directly to the susceptibility of the then dominant species to hurricane and storm damage and to diseases, and indirectly to the prevalent regime of high illumination, low turbulence, limited water flushing, and higher incidence of anthropogenic activities. It appears that part of the destruction of *A. cervicornis* and *A. palmata* in the lagoon was due to storm damage, but the epidemic white band disease which occurred in the Caribbean on Acroporid corals in the early 1980s (Peters, 1984), may have also been responsible. In contrast to the virtually total disappearance of *A. cervicornis* in shallow reefs of San Andrés, in other areas like Florida, Jamaica, Curaçao and Santa Marta (Colombia), where there were also mass mortalities of this species, there remained small populations that apparently are in the process of recovery (Bak & Criens, 1981; Jaap et al., 1988; Knowlton et al., 1990 ; pers. obs.). This may indicate either that recolonization by larval immigration has not taken place due to the geographical isolation of San Andrés, or that the conditions for the re-establishment of this species are not yet appropriate.

As in Jamaica (cf. Hughes, 1994), in the overfished reefs of San Andrés, *Diadema* lived in high densities in shallow, well illuminated and relatively calm reef areas. Its disappearance in San Andrés around 1983 (cf. Lessios et al., 1984) also resulted in widespread frondose algal growth, and probably had a major role in additional coral death and recruitment inhibition from shading and smothering (cf. Sammarco, 1980; Liddell & Ohlhorst, 1988; Carpenter, 1990a; 1990b). Further algal increases could have been fueled locally by nutrients from sewage discharges and groundwater seepage (cf. Walker & Ormond, 1982; Cuet et al., 1988), and by the more recent overfishing of reef herbivores.

On the other hand, in the enclosed lagoonal areas of San Andrés, water flushing is restricted, causing high thermal stress during El Niño warming events or during calms associated to intense insolation, which may have produced coral bleaching and widespread tissue mortality (see Geister, 1992; Williams & Bunkley-Williams, 1990). Also, depending on the length of the warm period, lower rates of (natural or artificial) lesion regeneration and increased tissue mortality (Meesters & Bak, 1993), may have occurred. Apparently, susceptibility to coral diseases such as black band disease may have also increased in these warm periods (Rützler et al., 1983). Furthermore, the increased sedimentation rates and turbidity from anthropogenic activities may have made corals more susceptible to diseases (Peters, 1984), and may have retarded the regeneration of tissue lesions (Meesters et al., 1992), which probably increased in proportion as a result of the heavy boat traffic and diving activities.

The high energy, shallow spur and groove zone of the barrier reef at San Andrés was (Geister, 1977) and still is dominated by hydrocorals, zoanthids and crustose coralline algae. This lack of an apparently significant change in comparison to other reef zones could have several explanations. During heavy surge, damage occurring on the small *Millepora* branches could be quickly restored by fast growth and by reattachment after breakage (Denny et al., 1985). Thus, even though contemporaneous coral death rates may be high, instantaneous measurements yield low proportions of dead tissues. In general, probably owing to a combination of strong turbulence and high density of herbivorous fishes (cf. Lewis & Wainwright, 1985; Steneck & Dethier, 1994; Díaz-Pulido & Díaz, in press) frondose algae at the San Andrés barrier reef tend to be restricted to crevices and grow in between and beneath coral branches. The excessive algal growth apparently was not as high as other reef zones after the *Diadema* die-off presumably because this species was already scarce in this habitat. Perhaps the overfishing of carnivores has also increased herbivorous fish populations, although these may have been recently overfished as well. In addition, high energy zones are continuously flushed, even during periods of calms, making temperature increases and their associated effects on coral tissues moderate at most during warming events (Geister, 1992). This could explain the lower degree of mortality found in the *A. palmata* stands on the barrier reef outer base than in those of the lagoon (see Peters, 1984).

With localized exceptions, several sites of the leeward 20 m terrace and outer fore-reef terrace edge, and the outer slope show, when compared to shallow lagoonal areas, lower coral mortality levels. Since there are less herbivores in deep reef areas, which allow for a higher frondose algal cover, the *Diadema* demise apparently did not trigger further algal blooms due to low light levels (cf. Lewis & Wainwright, 1985; Morrison, 1988; Díaz-Pulido & Díaz, in press). The greater depths also imply lower turbulence during storms, and prevent heating-up and the associated stress during calms. Hurricanes (cf. Woodley et al., 1981), and mass bleaching events (cf. Williams & Bunkley-Williams, 1990; Shulman & Robertson, 1996, but see Lang et al., 1988) have had their greater impact in Caribbean shallow reef areas in comparison to deeper ones. Localized damage to deep areas of San Andrés was associated with local garbage and sewage discharges.

Algal proliferation

The mean values of frondose algal cover at San Andrés are fairly high when compared to those published from Barbados (0%), Curacao (0%), Santa Marta (Colombia)(0%), Jamaica (0.7 - 2.8%) and Venezuela (12.8%) (see Liddell & Ohlhorst, 1988). However, the last values were recorded before 1982, i.e., before the die-off of *Diadema* occurred. Records after the demise of *Diadema* measured in Alacran Reef, Mexico, amounted to 45.6% algal cover (Liddell & Ohlhorst, 1988). Fleshy algal cover on the reefs of the San Blas Archipelago rose from about 2% in 1983 to nearly 28% in 1990 (Shulman & Robertson, 1996). Recent estimates in some reefs of Santa Marta, subjected to high downward fluxes of sediments and raw sewage outflows, showed values of algal cover of 40-50% (see Zea, 1993, 1994). These estimates are as high as those measured in 1992 in some areas of San Andrés.

Gorgonian mortality

The mass mortality of *Gorgonia* in San Andrés was probably related to similar events which occurred in other areas of the southern Caribbean during the 1980s, whose origin is attributed to a highly specific pathogen (Guzmán & Cortés, 1984; Garzón-Ferreira & Zea, 1992). A less intense *Gorgonia* mortality event was recorded again during 1995 throughout most of the Caribbean (Nagelkerken et al., in press), and a putative pathogen was isolated and identified as a fungus of the genus *Aspergillus,* a typical soil inhabitant (Smith et al., 1996). Noteworthy, sea fan mortalities do not seem to have affected populations of Serrana Bank, belonging also to the archipelago and located about 240 km NE from San Andrés (Fig. 1)(Díaz et al., 1996).

Decrease of reef fish stock

Evidently, over-fishing is the prime reason for the dwindling stocks of reef fishes on the island. But it must be noted, however, that all the major environmental changes observed in the reefs during the past two decades had an impact on these biotopes that provide food and shelter to specialized reef fish species. It should also be noted that the large-scale destruction of the coastal mangrove communities and part of the seagrass flats by measures aimed to develop the island deprived many reef fishes of their preferred nursery and feeding grounds (Heald & Odum, 1970; Ogden, 1980). As a consequence, juvenile reef fishes may have been subjected to increased predation pressure, thus having less chance to grow to a reproductive age.

CONCLUDING REMARKS

As we have shown, remarkable biotic changes have occurred in the reef complex of San Andrés during the last two decades. Some changes, especially those involving coral decline, appear to be mainly related to the macroregional, well-documented, increasing degradation processes of reefs in the wider Caribbean (see Ginsburg, 1994; Hughes, 1994) caused, apparently, by both natural and human induced regional and global changes (chronic diseases of corals and other reef organisms, coral bleaching, increase in algal cover due to release of grazing pressure and to overall nutrient enrichment). However, increasing and poorly planned human activities on the island are directly or indirectly responsible for many of the recorded biotic changes.

For example, over-exploitation of commercial organisms causes reduction in populations of some fishes and invertebrates, leading to disarrangement of trophodynamic processes which are yet not well understood, but whose effects may become evident, such as the increase in cover of fleshy algae. Because of the lack of an adequate sewage system, the increase of nutrient availability in sea water also stimulates algal blooms and reduces coral cover on reefs.

San Andrés serves as a good example of the phenomenon of over-development and poor planning on small islands. It developed from a small nucleus of fishermen and coconut planters to a major tourist resort and commercial center in the brief space of 25 years, during which the sharply increasing population and numbers of tourists and associated large investment to meet infrastructure requirements led to disorderly land development and serious urban problems. The growing recreational tourism at San Andrés is greatly based on attractive seascapes and a "healthy" marine environment. However, as has been shown, the consequences of unplanned development and largely unrestrained over-fishing can also be clearly traced in the marine environment. Since, direct uses of the reef complex depend for their sustainability upon the ability of reef environments to provide opportunities in the form of harvestable resources or of quality sites for non-extractive activities (cf. Kenchington, 1988), it seems clear that if the processes causing man-induced degradation of the marine environment continue, the major economic income-producing activity of San Andrés will soon be seriously threatened.

ACKNOWLEDGMENTS

The authors express their gratitude to Juan A. Sánchez and Martha Prada for assistance in the field surveys. We extend our appreciation to Dr. Robert N. Ginsburg for his helpful discussions and contribution to the improvement of the manuscript. This study has been funded by INDERENA, CORPES C.A., INVEMAR, Universidad Nacional de Colombia, Instituto Colombiano de Ciencia y Tecnología (COLCIENCIAS, Grant No. 2105-09-023-93) and the Department of Foreign Affairs (EDA/DEH) at Bern, Switzerland. This is contribution No. 605 of the Instituto de Investigaciones Marinas y Costeras, INVEMAR.

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Table 1. Distribution of live coral (relative to hard substrata) , recently dead coral (relative to total coral cover, live+dead) and algal cover (percent frondose algae in parenthesis) at San Andrés, estimated from visual surveys (visual) and chain transect surveys (trans.) carried out in 1992. (+) = present, but cover<5%; (-) = no data.

Reef zone/	Live coral (%)		Recently dead coral (%)		Algae (%)	
station	visual	trans.	visual	trans.	visual	trans.
Barrier, back reef						
3	35	-	60	-	65(10)	-
17	22	-	70	-	72(11)	-
29	43	-	90	-	50(+)	-
34	20	-	70	-	78(17)	-
Barrier, fore-reef slope (spur and groove)						
2	22	-	40	-	74(11)	-
6	35	46	10	32	35(5)	29(4)
18	40	45	20	40	45(13)	42(19)
23	40	-	20	-	30(5)	-
30	30	-	10	-	55(+)	-
35	30	16	20	43	40(5)	72(24)
37	25	-	30	-	75(15)	-
Windward inner fore-reef terrace						
5	26	-	30	-	60(10)	-
31	53	-	50	-	42(+)	-
Windward middle fore-reef terrace						
4	22	-	30	-	72(6)	-
24	20	-	40	-	60(20)	-
Windward outer fore-reef terrace (edge-slope)						
19	17	-	70	-	75(75)	-
25	15	26	60	53	80(30)	61(22)
32	50	-	50	-	55(19)	-
36	25	23	30	54	70(40)	73(21)

(Continued on the next page)

Table 1 (continued from previous page)

Reef zone/	Live coral (%)		Recently dead coral (%)		Algae (%)	
station	visual	trans.	visual	trans.	visual	trans.
Lagoonal *A. palmata-Diploria-Millepora* reefs						
7	30	-	80	-	70(5)	-
9	30	-	70	-	70(15)	-
11(flat)	30	-	-	-	70(50)	-
11(crest)	28	-	60	-	72(33)	-
12	33	-	60	-	67(39)	-
13(flat)	35	-	-	-	65(35)	-
13(crest)	33	-	60	3[*]	67(45)	54(9)
27	21	9	70	5[*]	79(5)	90(38)
33	5	-	90	-	95(5)	-
28	21	29	50	44	79(21)	66(12)
Lagoonal *Montastraea-Siderastrea* deep reefs and shallow reef bases						
8	50	38	60	61	50(25)	57(47)
21(base)	22	-	50	-	78(22)	-
22(flat)	-	-	90	-	-	
22(base)	38	21	30	52	62(-)	69(41)
26	7	-	60	-	86(29)	-
10	40	-	70	-	60(40)	-
Leeward 4 m terrace						
38	20	16	30	53	80(10)	78(8)
41	12	-	35	-	88(14)	-
43	10	-	30	-	90(45)	-
44	5	-	60	-	90(50)	-
46	5	-	50	-	95(-)	-
47	15	-	30	-	80(-)	-
Leeward 20m terrace						
39	56	41	35	57	44(38)	51(39)
40	25	-	-	-	-(-)	-
42	38	-	45	-	56(56)	-
45	29	14	60	84	58(58)	80(62)
48	21	-	60	-	79(79)	-
Mean	26	30	52	44	68(25)	62(26)

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[*] Data not comparable with visual estimation

Table 2. Species-specific coral mortality levels at San Andrés in 1992. Range and mean of per-station proportion of dead coral (percent of dead relative to live + dead coral), and percent frequency of mortality (number of stations with dead tissues/number of total stations where the species was found).

	Proportion (%)		
Species	Range	Mean	Frequenc
Acropora cervicornis	0 -100	75.0	75
A. palmata	0 - 95	59.2	89
Agaricia agaricites	0 - 80	6.8	24
Colpophyllia natans	30 - 70	52.9	100
Dendrogyra cylindrus	0 - 30	8.0	40
Dichocoenia stokesi	0 - 70	13.8	50
Diploria clivosa	0 - 30	5.2	23
D. labyrinthiformis	0 - 40	17.1	60
D. strigosa	0 - 60	16.4	58
Eusmilia fastigiata	0 - 80	52.5	75
Isophyllastrea rigida	0 - ?	?	11
Meandrina meandrites	0 - 40	8.8	25
Millepora complanata	0 - 90	31.3	70
Montastrea annularis	0 - 90	37.5	81
M. cavernosa	0 - 70	22.3	73
Porites furcata	0 -100	25.9	41
P. porites	0 - 70	21.5	48
Siderastrea siderea	0 - 80	31.7	74
Stephanocoenia	0 - 50	16.7	29
Gorgonia sp.	60 -100	91.4	100

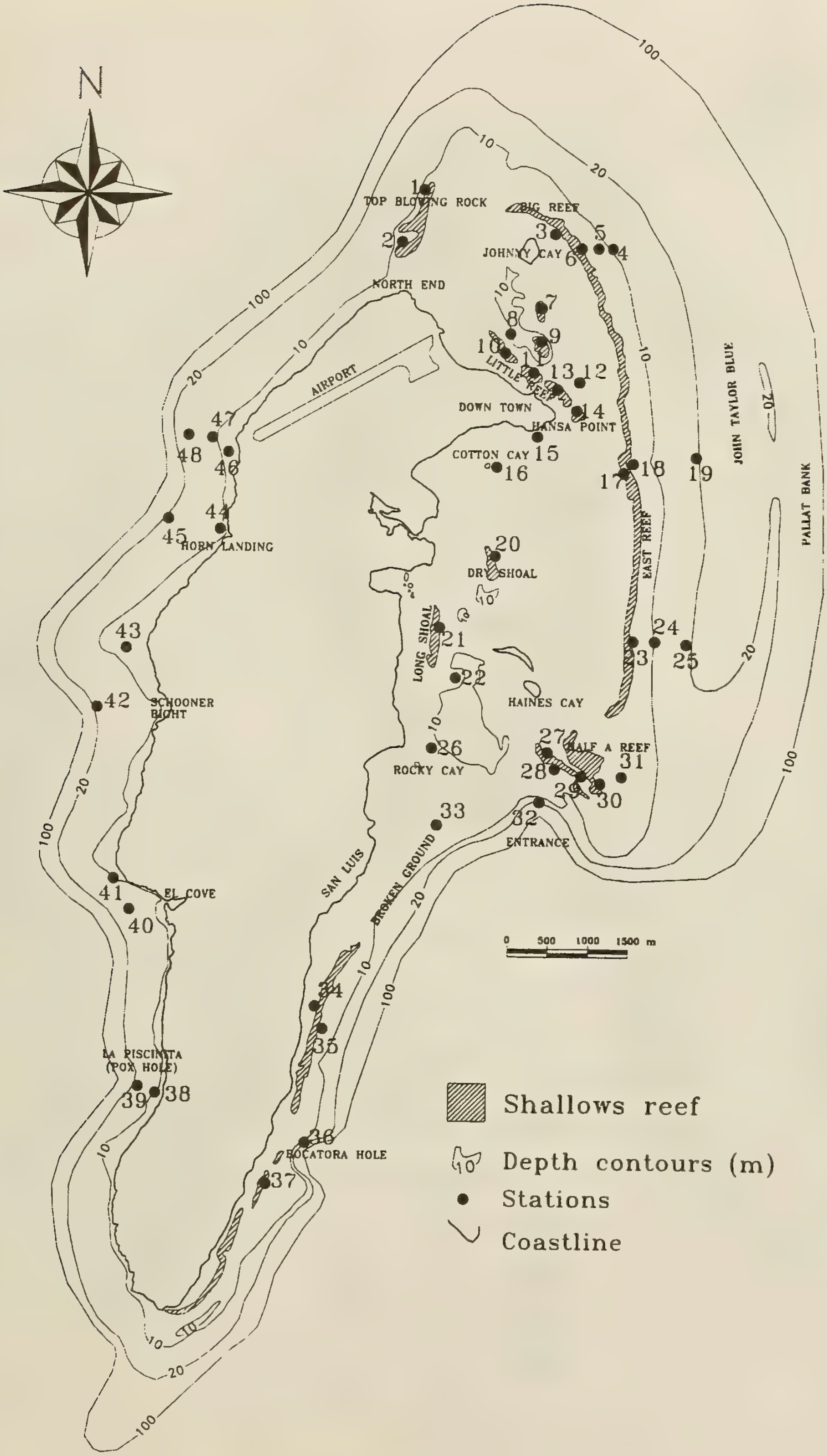
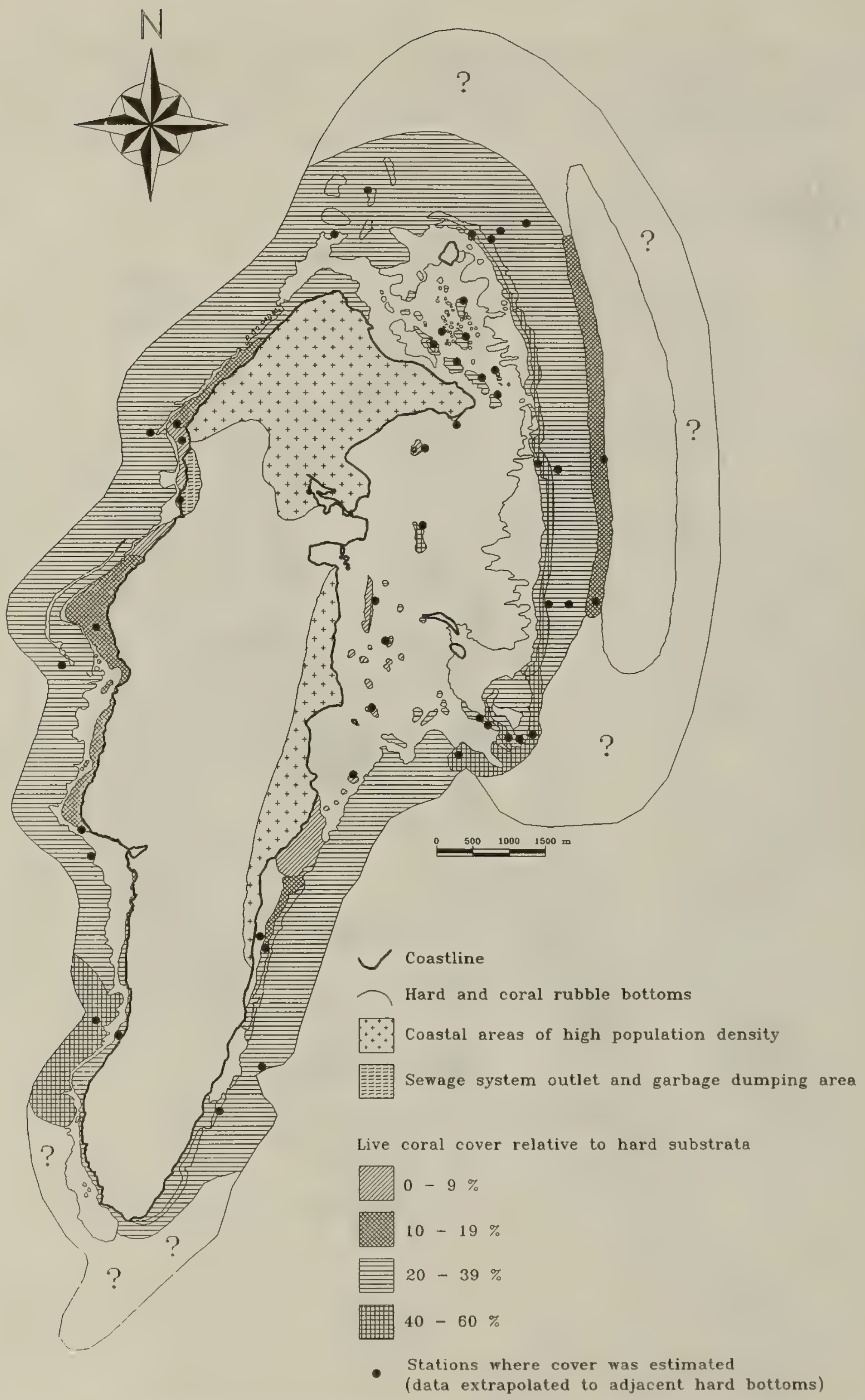


Figure 2. Topographic features of the insular shelf of San Andrés and location of stations where quantitative data on coral and algal cover were obtained in 1992.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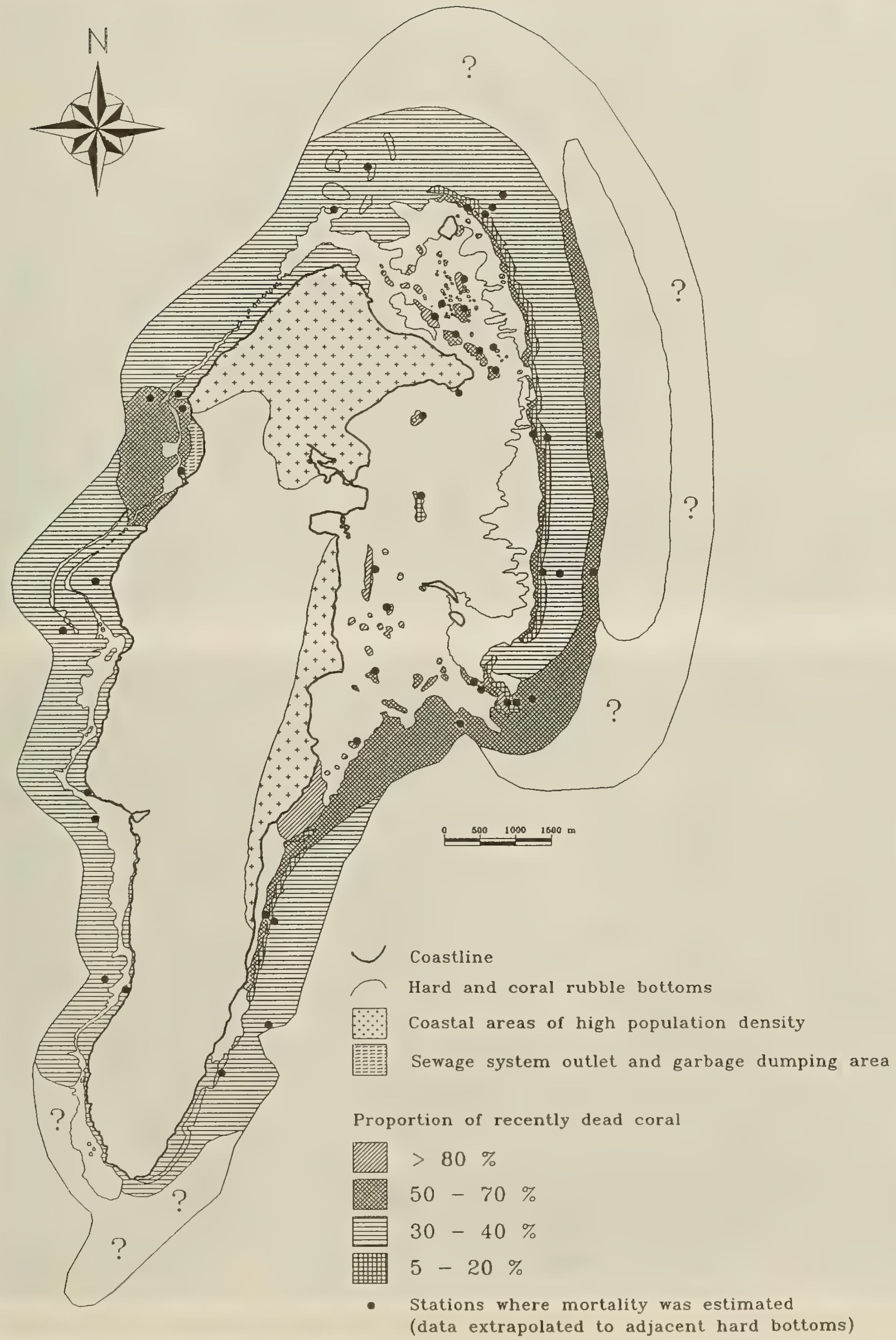
0 500 1000 1500 m
Coastline
Hard and coral rubble bottoms
Coastal areas of high population density
Sewage system outlet and garbage dumping area
Live coral cover relative to hard substrata
0 - 9 %
10 - 19 %
20 - 39 %
40 - 60 %
Stations where cover was estimated
(data extrapolated to adjacent hard bottoms)

Figure 3. Distribution of live coral cover (relative to hard substrata) at San Andrés.


N
?
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0 500 1000 1500 m
Coastline
Hard and coral rubble bottoms
Coastal areas of high population density
Sewage system outlet and garbage dumping area
Proportion of recently dead coral
> 80 %
50 - 70 %
30 - 40 %
5 - 20 %
Stations where mortality was estimated
(data extrapolated to adjacent hard bottoms)

Figure 4. Distribution of the proportion of recently dead coral (relative to total, live+dead, coral).

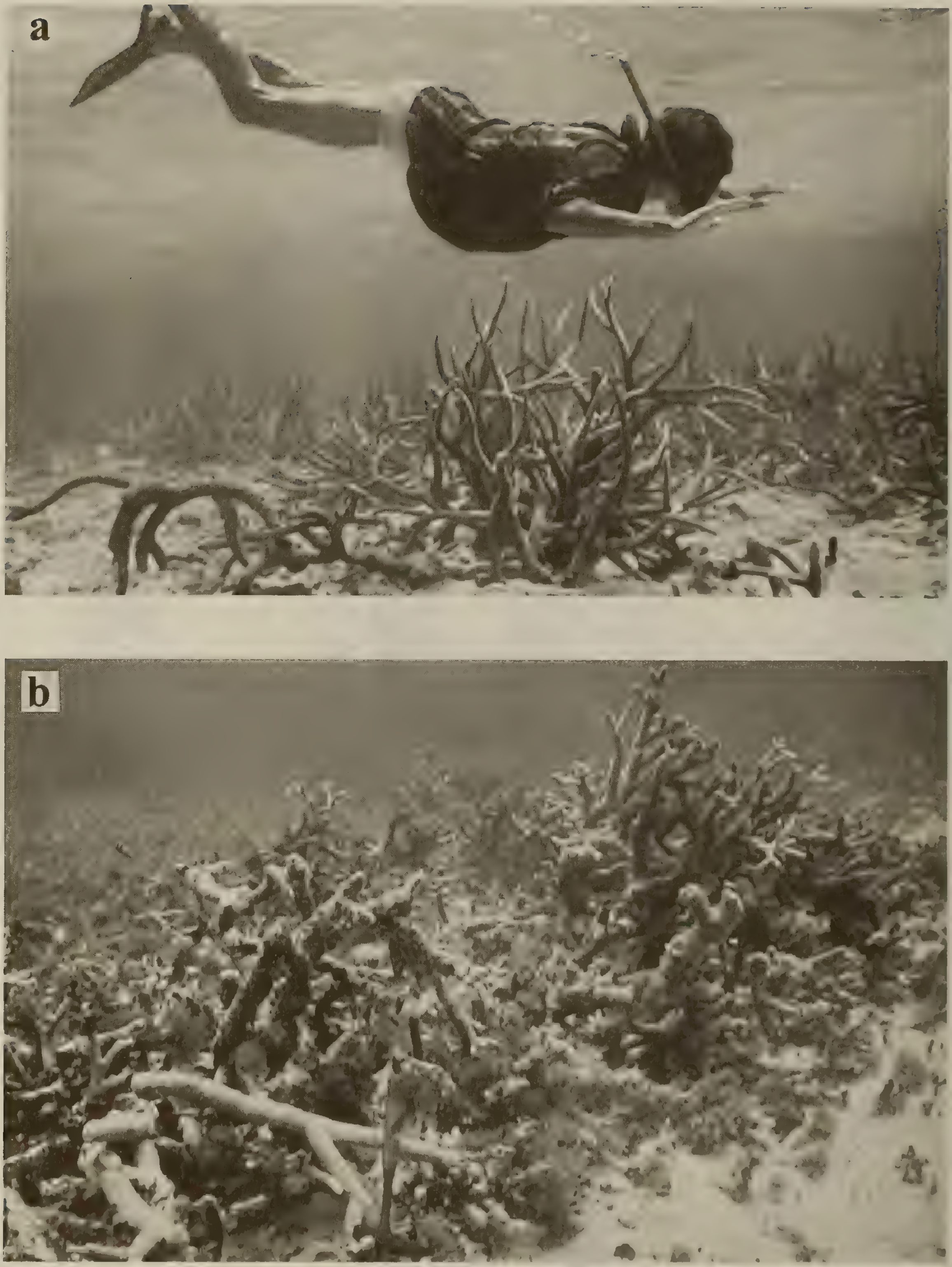
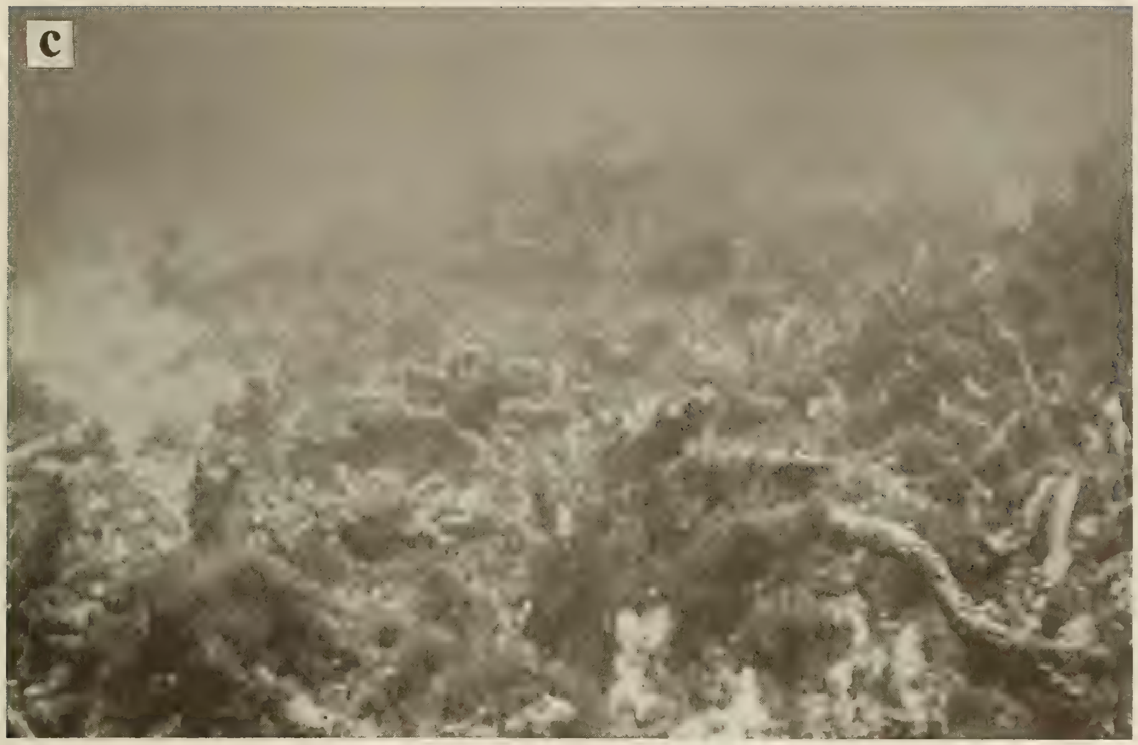


Figure 5 (continued on the next page). *Acropora cervicornis* stands in the northern lagoonal basin of San Andrés, 1-2 m in depth. **(a)** 1970, live, healthy thickets. **(b)** 1977, partly necrose and covered by filamentous algae.



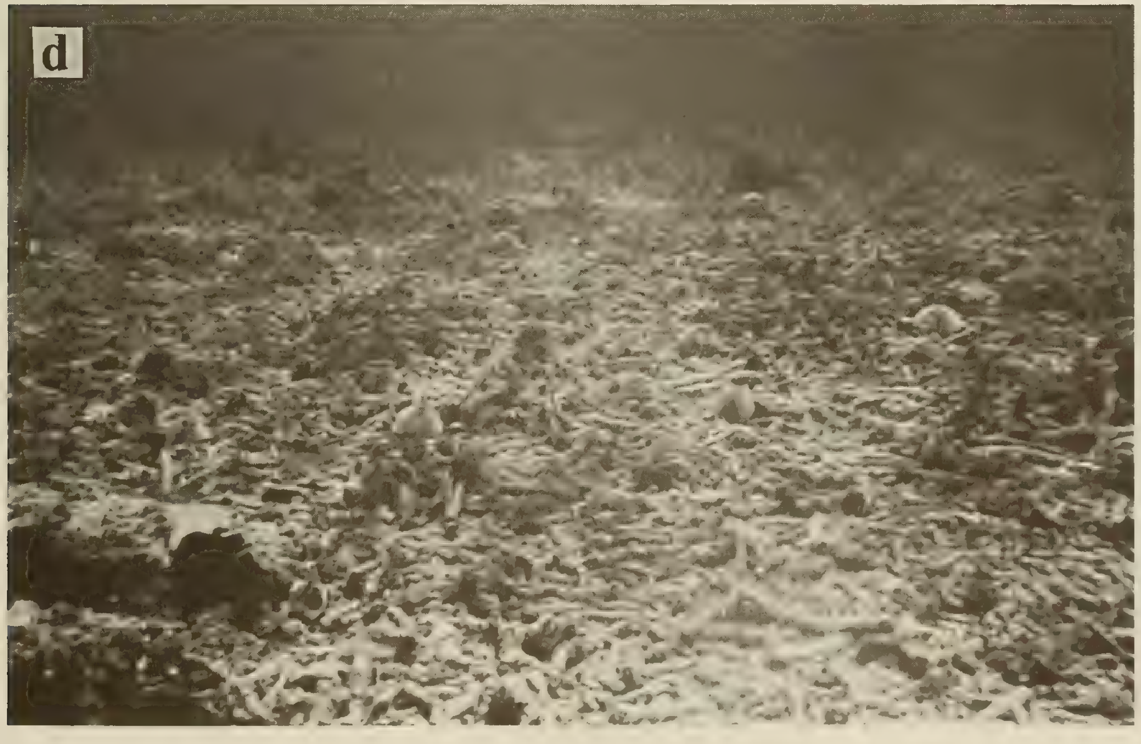


Figure 5 (continued from the previous page). **(c)**. 1979, more than 80% of coral tissues dead. **(d)** 1992, 100% mortality and collapse of skeletons.

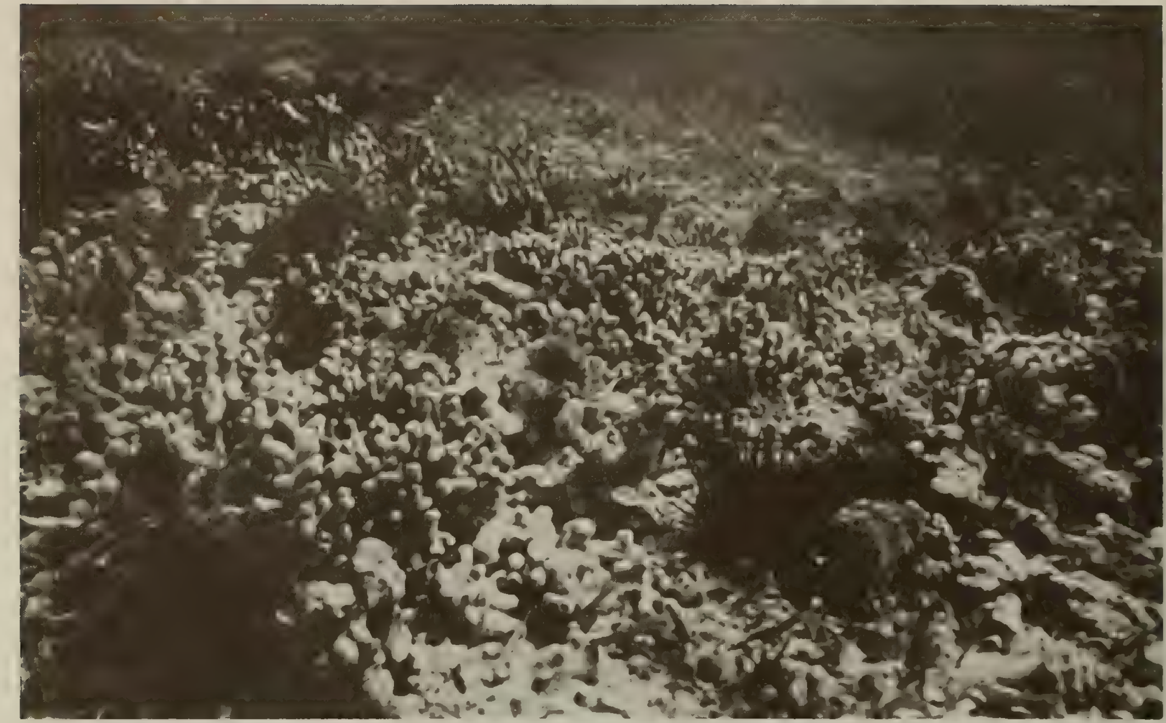


Figure 6. Shallow reef at Cotton Cay with live *Porites furcata* and the long-spined urchin *Diadema antillarum*, 0.5 m in depth, 1992.

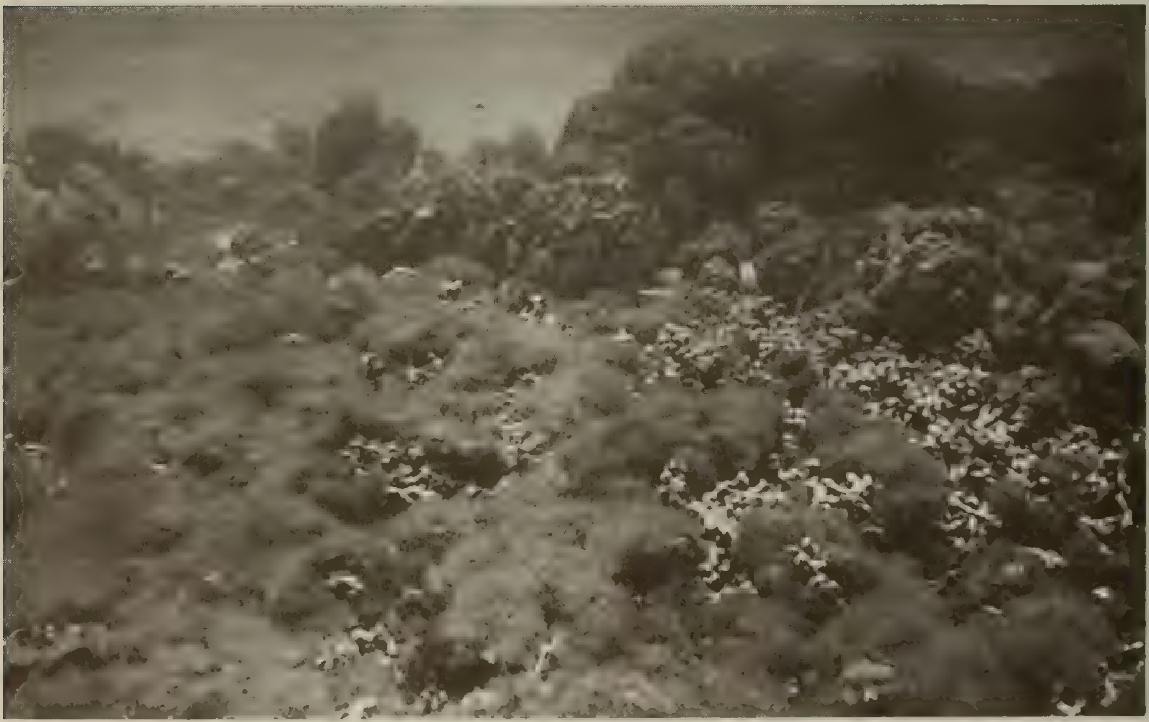


Figure 7. Coral patch in the northern lagoonal basin of San Andres, 1-3 m, 1992. The carpets of the finger coral *Porites porites* are densely covered by brown algae (Dictyotaceae)

ATOLL RESEARCH BULLETIN

NO. 457

RAPID ECOLOGICAL ASSESSMENT OF THE CAYOS MISKITOS MARINE RESERVE WITH NOTES ON THE SHALLOW-WATER STONY CORALS FROM NICARAGUA

BY

STEPHEN C. JAMESON

ISSUED BY
NATIONAL MUSEUM OF NATURAL HISTORY
SMITHSONIAN INSTITUTION
WASHINGTON, D.C., U.S.A.
SEPTEMBER 1998

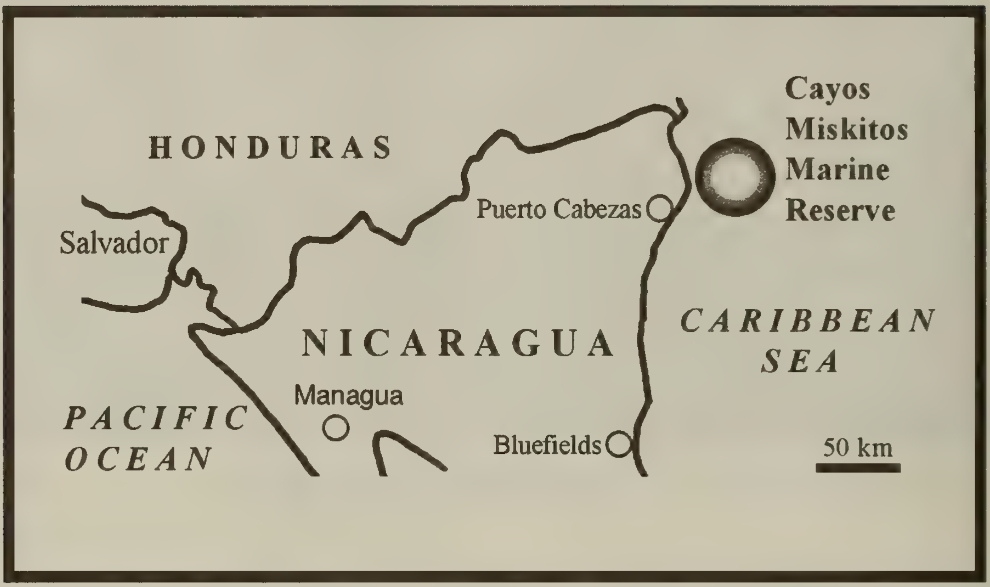


Figure 1. Regional map showing the location of Cayos Miskitos Marine Reserve off the Caribbean coast of Nicaragua. Puerto Cabezas was used as the headquarters for survey operations.

RAPID ECOLOGICAL ASSESSMENT
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SHALLOW-WATER STONY CORALS FROM NICARAGUA

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STEPHEN C. JAMESON[1]

ABSTRACT

At the present time, most of the coral reef ecosystem of the Miskito Coast Marine Reserve is in good condition. However, increased sedimentation and eutrophication, as well as a reduction in fish abundance, could easily tip the balance toward an unhealthy condition. Sedimentation and eutrophication are stressing reefs closest to the Honduran border (northwest reefs). Other reefs are experiencing higher than normal sedimentation but are viable. The abundant and diverse herbivorous fish populations help keep algal overgrowth in check. High lobster and turtle fishing pressure is severely stressing these populations. While lobster populations seem to be maintaining themselves, albeit at a young age-class population structure, this is probably not the case for turtle populations. The remote location of the Cayos Miskitos reefs has saved them from the fate of most Caribbean reefs near large population centers. Natural storm damage, has caused most of the physical change on the reefs, but this in turn has provided new habitat for the abundant coral recruits and is part of the natural evolution of the coral reef ecosystem. Twenty-seven shallow-water stony coral species were collected during the survey. This list could be increased with more field effort. Considering the habitat availability and favorable environmental conditions all Caribbean coral species should be found in the Cayos Miskitos Marine Reserve. This is the first listing of stony coral species from the Caribbean coast of Nicaragua.

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Manuscript received 5 August 1998; revised 18 August 1998

INTRODUCTION

The purpose of this three day USAID Environmental Initiative of the Americas (EIA) fisheries project expedition in Nicaragua was to make a rapid assessment of the condition of the coral reef ecosystem of the Miskito Coast Marine Reserve (Figure 1), determine coastal issues that directly affect coral resources of the area, identify the dominant coral species in the Reserve, and prepare a comparative analysis of similar areas and conditions. Recommendations for management to adequately protect the coral resources of the Cayos Miskitos Marine Reserve are provided. Voucher stony coral and gorgonian collections were made for the Nicaragua natural resources ministry (MARENA) and for the Smithsonian Institution National Museum of Natural History.

METHODS

Surveys were conducted off the 10 m vessel PALPA using scuba and by snorkeling. Underwater and topside photographs were taken to document habitats, biota and users. Navigational fixes were obtained using GPS. Reef condition assessments were made based on field experience in other areas of the Caribbean, by interviewing local fishermen, government officials and local environmental NGO staff and by consulting and coordinating with other EIA team members (Trott 1996) involved in ancillary surveys. Stony coral identifications were made by the author. The black coral identification was made by Dennis M. Opresko.

THE HABITATS

Cayos Miskitos Marine Reserve coral reefs vary from small patches and pinnacles to large complicated platforms (tens of meters in diameter) and well-defined belts (kilometers wide). Some reefs are close enough to sea level to be observed from the surface and some are even exposed at low tide (Roberts and Murry 1983). The intricate structure of the Cayos Miskitos coral reef makes it a perfect habitat for lobster and other commercially important fin and shellfish. During this expedition four coral reef areas were surveyed (Figure 2).

1. Nasa Reef

Date: April 30, 1996
Location: 14°18.43'N, 82°57.20'W
Depth: 1 - 2 m
Dominate coral species: *Acropora palmata, Montastraea annularis, Millepora complanata, Porites astreoides*

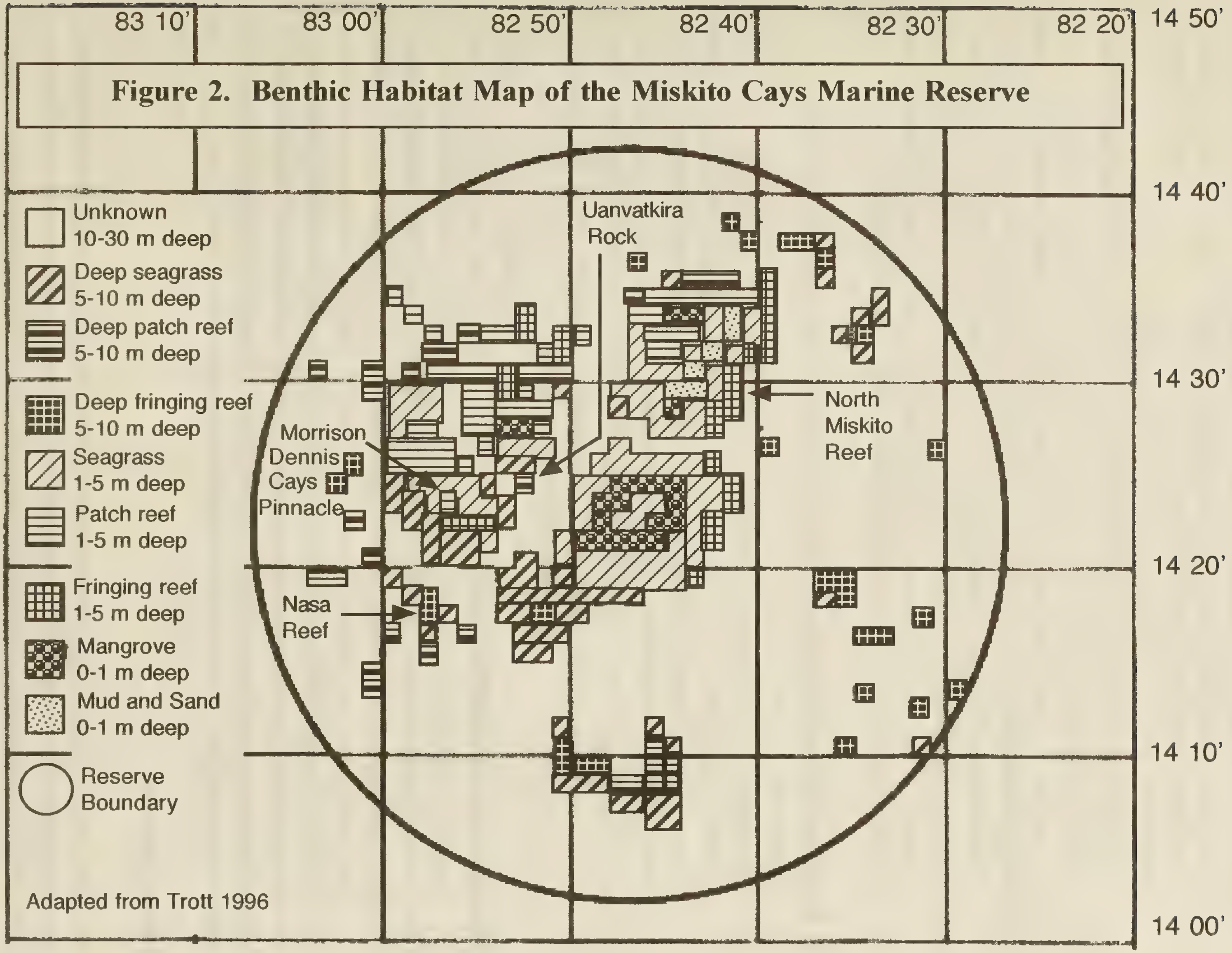

Figure 2. Benthic Habitat Map of the Miskito Cays Marine Reserve

Adapted from Trott 1996

2. **Uanvatkira Rock**
   Date: May 1, 1996
   Location: 14°25.30'N, 82°52.50'W
   Depth: 3 - 4 m
   Dominate coral species: *Acropora palmata, Porites astreoides, Porites porites, Diploria clivosa*

3. **North Miskito Reef**
   Date: May 1, 1996
   Location: 14°29.60'N, 82°41.80'W
   Depth: 1 - 4 m
   Dominate coral species: *Acropora palmata, Millepora complanata*

4. **Morrison Dennis Cays Pinnacle**
   Date: May 2, 1996
   Location: 14°24.22'N, 82°57.16'W
   Depth: 10 - 15 m.
   Dominate coral species: *Montastraea cavernosa, Montastraea annularis, Porites porites, Porites astreoides, Agaricia agaricites*

COASTAL ISSUES

Sedimentation and Eutrophication

The Cayos Miskitos lie about 50 km from Puerto Cabezas and represent the northern most coral reef ecosystems off the coast of Nicaragua.

Water turbidity is relatively high (average visibility 10 m). NOAA satellite imagery shows that most of the sedimentation and eutrophication affecting the Miskito Coast Marine Reserve comes from the Honduran coast where coastal deforestation combined with heavy rainfall and river inputs contribute to this situation.

Fishing Impacts

No turtles were sighted during the expedition providing qualitative evidence that fishing pressure is very high. Upon landing back at Puerto Cabezas there were over a dozen green turtles captured and being held alive on the beach. They are sold locally as a beef/pork substitute. A sampling of shallow water (snorkel depths) lobster populations found specimens less than a year old and not in great abundance.

Reef fish populations do not appear to be heavily impacted by fishing, However, there is concern that the aquarium fishery developing at Corn Island may expand into the Reserve (Marshall 1996).

Anchor Damage

Most of the vessels using the Cayos Miskitos Marine Reserve are light weight and not abundant, so at present, anchor damage to the coral reef is light compared to other Caribbean reefs with high recreational use. Anchor damage is small compared to the natural storm damage that has occurred. However, steps should be taken to reduce this easily controlled impact through the installation of mooring buoys.

REEF CONDITION AND QUALITATIVE COMPARATIVE ANALYSIS

Indicators of Good Reef Condition

- *Coral recruitment high*

There was clear evidence of young coral recruits in all areas. The frequency of storms undoubtedly produces abundant new habitat for coral settlement.

- *Healthy reef fish populations*

Reef fish populations were in fairly good shape and reflect the habitat in which they are found (Marshall 1996). Populations were characteristic of a more remote Caribbean location that has experienced less intense fishing pressure. Species diversity and abundance was relatively high - much more so than in coral reef ecosystems near large population centers in other parts of the Caribbean where spear and trap fishing have decimated populations and allowed algal overgrowth of coral reefs (Jameson et. al. , 1995). There was evidence of commercial species (i.e., jewfish, snappers, groupers, parrot fish). Sharks (*Carcharinus perezi* and *Ginglymostoma cirratum*) were seen on the reef during the day and were also abundant at night which is a good indicator of a healthy ecosystem.

- *High algal diversity*

The diversity of algae was high in all the coral reefs surveyed. On most reefs surveyed there was no indication of fleshy macroalgae dominating. The abundance of seagrass beds (*Thalassia testudinum* and *Syringodium filiforme*) provides a luxuriant habitat for sea turtle and other species.

- *Little coral disease*

No corals were observed with active disease. During the survey less than 20 colonies were sited that had experienced disease in the past.

- *Little coral bleaching*

Only a single colony of *Agaricia agaricites* and a single colony of *Siderastrea radians* were observed to be bleached.

- *Normal sea urchin densities*

The abundance of sea urchins appeared in balance with the ecosystem.

- *Little anchor damage*

Most vessels using the Reserve are light-weight sailing boats. During the day they are anchoring on the coral reef, but at night most tie up to a casitas.

Indicators of Stress

- *High turbidity*

Visibility was poor (less than 10 meters) compared to most other Caribbean marine parks. Most coral specimens with flat growth forms showed an unusually large amount of sediment on their exterior surface. Bottom sediments were fine grained and easily stirred-up, creating low visibility.

- *Eutrophication effects*

Overgrowth of corals by fleshy macroalgae was seen on northwest reefs (closest to the Honduran border).

- *Lobster population overfished*

Specimens were small in size and not abundant in shallow water.

- *No turtles observed*

No turtles were observed by any members of the team during the expedition. Local net fishing methods are very effective.

- *Storm damage evident*

Storm damage was evident on all reefs, but more so on seaward reefs.

Diagnosis

Sedimentation and eutrophication are stressing reefs closest to the Honduran border (northwest reefs). Other reefs are experiencing higher than average sedimentation but are viable. The abundant and diverse herbivorous fish populations help keep algal overgrowth in check. The high lobster and turtle fishing pressure is severely stressing these populations. While lobster populations seem to be maintaining themselves, albeit at a young age-class population structure (Childress and Herrnkind 1996), this is probably not the case for turtle populations.

At the present time, most of the coral reef ecosystem of the Cayos Miskitos Marine Reserve is in good condition. However, increased sedimentation and eutrophication, as well as a reduction in fish abundance, could easily tip the balance toward a stressed condition. The remote location of the Cayos Miskitos reefs has saved them from the fate of most Caribbean reefs near large population centers. Natural storm damage, has caused most of the physical change on the reefs, but this in turn has provided new habitat for the abundant coral recruits and is part of the natural evolution of the coral reef ecosystem.

CORAL SURVEY

The following twenty-seven stony coral species were collected during the survey (Table 1). Without doubt, this list could be increased with more field effort. Considering the habitat availability and favorable environmental conditions all Caribbean coral species should be found in the Cayos Miskitos Marine Reserve. A voucher collection was left in Puerto Cabezas with MARENA officials along with identification keys and collecting materials. A voucher collection was also made for the Smithsonian Institution National Museum of Natural History (USNM). This is the first listing of stony coral species from the Caribbean coast of Nicaragua.

A sample of 12 gorgonian species was also collected. Gorgonian specimens were left with MARENA officials in Puerto Cabezas and specimens were also taken to the Smithsonian for identification. One specimen of black coral was identified and cataloged into the USNM collection (*Stichopathes occidentalis* Brook [USNM 99350]).

Table 1. Shallow-water stony coral specimens from the Caribbean coast of Nicaragua. Smithsonian Institution National Museum of Natural History catalog numbers: USNM 99321 - 99349.

Class HYDROZOA
    Order MILLEPORINA
        Family MILLEPORIDAE
            Millepora alcicornis Linnaeus, 1758 [USNM 99338]
            Millepora complanata Lamarck, 1816 [USNM 99338]
Class ANTHOZOA
    Order SCLERACTINIA
        Suborder ASTROCOENIINA
            FAMILY POCILLOPORIDAE

    - *Madracis mirabilis* (Duchassaing and Michelotti, 1860) [USNM 99326]
    - *Madracis decactis* (Lyman, 1859) [USNM 99342]
  - Family ACROPORIDAE
    - *Acropora cervicornis* (Lamarck, 1816) [USNM 99332]
    - *Acropora palmata* (Lamarck, 1816) [USNM 99323]
    - *Acropora prolifera* (Lamarck, 1816) [USNM 99346]
- Suborder FUNGIIDA
  - Family AGARICIIDAE
    - *Agaricia agaricites* (Linnaeus, 1758) [USNM 99321 and 99348]
    - *Agaricia temuifolia* (Dana, 1848) [USNM 99328]
    - *Leptoseris cucullata* (Ellis and Solander, 1786) [USNM 99349]
  - Family SIDERASTREIDAE
    - *Siderastrea siderea* (Ellis and Solander, 1786) [USNM 99334]
    - *Siderastrea radians* (Pallas, 1766) [USNM 99335]
  - Family PORITIDAE
    - *Porites porites* (Pallas, 1766) [USNM 99339]
    - *Porites furcata* Lamarck, 1816 [USNM 99345]
    - *Porites divaricata* Lesueur, 1821 [USNM 99343]
    - *Porites astreoides* Lamarck, 1816 [USNM 99337]
- Suborder FAVIINA
  - Family FAVIIDAE
    - *Favia fragum* (Esper., 1795) [USNM 99344]
    - *Diploria clivosa* (Ellis and Solander, 1786) [USNM 99322]
    - *Diploria strigosa* (Dana, 1848) [USNM 99327]
    - *Manicina areolata* (Linnaeus, 1758) [USNM 99347]
    - *Montastraea annularis* (Ellis and Solander, 1786) [USNM 99329 and 99336]
    - *Montastraea cavernosa* (Linnaeus, 1767) [USNM 99330]
  - Family MEANDRINIDAE
    - *Meandrina meandrites* (Linnaeus, 1758) [USNM 99340]
  - Family MUSSIDAE
    - *Isophyllastrea rigida* (Dana 1848) [USNM 99331]
    - *Scolymia lacera* (Pallas, 1766) [USNM 99333]
    - *Mycetophyllia danaana* Milne Edwards and Haime, 1849 [USNM 99325]
- Suborder CARYOPHYLLIINA
  - Family CARYOPHYLLIIDAE
    - *Eusmilia fastigiata* (Pallas, 1766) [USNM 99324]

MANAGEMENT RECOMMENDATIONS

The following recommendations are limited to the marine component of the Miskito Coast Marine Reserve because, during my short visit, I was not able to visit the land component.

1. Focus the purpose of the Cayos Miskitos Marine Reserve on marine biodiversity conservation and research. Ecotourism and recreational diving/snorkeling should be only a minor focus. This conclusion is based on the following analysis of the strengths and weaknesses of the area.

Weaknesses:

Unlike most marine protected areas in the Caribbean that have a strong recreational focus, the Cayos Miskitos Marine Reserve does not lend itself to attract large numbers of ecotourists or sport divers for the following reasons.

- The unsafe pier facilities and rough harbor wave conditions make commercial dive boat operations unavailable and unfeasible in the future.
- It is a very rough 4+ hour boat ride to the Cays and reefs when conditions are good.
- The high water turbidity provides a low quality dive experience in most cases.
- The lack of any tourist class hotel or restaurant facilities discourages visitors. In addition, the present modest hotel accommodations are very limited in capacity.
- For most tourists, water and food must be consumed with special precautionary procedures.
- The airline transportation from Managua to Puerto Cabezas does not meet common safety standards and baggage handling is unreliable.
- The long rainy season (May - October) does not provide an attractive tourist climate or lend itself to pleasant marine operations.
- The chance of getting malaria and/or dengue fever from mosquitoes is always present. Precautions to reduce this risk are not attractive to most tourists looking for a relaxing vacation.

Strengths:

Unlike many coral reef ecosystems in the Caribbean, the Cayos Miskitos Marine Reserve is a remote ecosystem that is not being stressed by man to the point of major or irreversible degradation. Positive environmental indicators include the following:

- Reef fish populations are relatively diverse and abundant. There are no large-scale commercial fishing enterprises operating in the area.
- Coral populations are for the most part in good condition and recruitment is evident. Coral disease and bleaching are minimal.
- The local fishermen, the predominate users of the area, are not causing major negative impacts to the ecosystem via physical damage to the coral reef.

- While there is overfishing of lobster and turtle by the local inhabitants, this can be managed effectively through regulation and enforcement.
- There is no expected large increase in the number of users.
- There is no expected change in the type of user (fishermen).
- There is no significant sport diving use of the area.

To accomplish the purpose stated above I recommend that Reserve regulations be centered around two types of permanent zones within the reserve.

1. **Harvest refugia zones** - where no entry is allowed except by permit. These zones should be strategically placed within the reserve in several locations. Demarcation buoys should be installed to locate these zones. These zones would not only insure the conservation of biodiversity and breeding stock (especially important for maintaining viable lobster and turtle populations) but would also seed neighboring multi-use areas and help maintain commercial and sport harvesting enterprises (Davis et. al., 1991). Harvest refugia areas would also provide unique laboratories for scientists studying the evolution and characteristics of minimally impaired coral reef ecosystems and the value of harvest refugia.

2. **Multi-use zones** - where fishing is allowed along with other appropriate activities.

The following temporary zones could also be specified in the regulations and used, as needed, to provide flexibility to the zoning system and provide for more effective management.

- **Closed Areas** - to allow for research or recovery of the living resources.
- **Limited Access Areas** - with the following designations and corresponding objectives.

(a) **"Recovery areas"** to provide for the recovery of Reserve resources from degradation or other injury attributable to human uses.

(b) **"Restoration areas"** to provide for restoration of degraded or otherwise injured resources.

(c) **"Research-only areas"** to provide for scientific research or education relating to protection and management.

(d) **"Facilitated-use areas"** to provide for the prevention of use or user conflicts or the facilitation of access and use, or to promote public use and understanding, of reserve resources through the issuance of special-use permits.

2. Give as much management and enforcement authority as possible for the Cayos Miskitos Marine Reserve to the Miskito Indians. These lands and waters have been their territory for thousands of years. They are the prime users of the Reserve and were instrumental in its creation. They have the desire to maintain the viability of the ecosystem for their long-term fishing use and are capable of creating a self-enforcement mechanism.

Before regulations can be drafted it must be clear who will be in charge of the Cayos Miskitos Marine Reserve. The Nicaraguan constitution divides the Atlantic Coast into two autonomous regions, each with its own regional government. However, there is no common agreement on the role of each. In addition, the waters of the Cayos Miskitos Marine Reserve were not included in the autonomy plan that created the two regional governments. The central government believes it should regulate and manage all natural resources including those off the Caribbean coast and grant official permits for resource exploitation. Regional governments disagree and insist that they should be in charge. Miskito Indians from local communities argue that they are never consulted by any level of government and demand a say in who uses the resources and how. The disorderly conditions created by these misunderstandings have been both embarrassing for the central and autonomous governments and painful for the local indigenous people.

On top of this, conflicts between the Miskito Indians and Honduran poachers have led to violence. The Nicaraguan Navy plans to enlarge its enforcement fleet from one to three vessels, with one stationed at the Honduran border. Miskito Indian Reserve enforcement rangers could work in conjunction with the Navy to enforce reserve regulations.

Until clear management authority is agreed upon and designated for the Cayos Miskitos Marine Reserve the process of drafting regulations and a management plan can not effectively go forward.

3. Create a high quality poster for the Cayos Miskitos Marine Reserve. The poster will help solidify the image of the reserve in the minds of policy makers and stake-holders and can be used as an effective publicity and fund-raising tool. It will also show that the creation of the reserve is now in “new hands”. It would be one of the best initial investments in getting the reserve off on the right foot as it helps create an identity.

4. In a democratic Nicaragua, a draft environmental impact statement (EIS) that evaluates a range of reasonable alternative approaches to Reserve management should be produced. The alternatives should be presented in comparative form to facilitate analysis of their effects. The preferred alternative for Reserve management should be presented based on the management authorities analysis of its impacts. A draft management plan for the preferred alternative should be produced that includes draft regulations. Draft regulations should be produced working closely with the management

authority. The "Preliminary Management Plan" produced by the Caribbean Conservation Corporation is a good feasibility study and can be of use in drafting the above documents. Public hearings should be held to discuss the Draft EIS/Management Plan and appropriate comments incorporated into the FinalEIS/Management Plan.
Detailed face-to-face discussions between the EIS/Management Plan writer and the Reserve management authority are the quickest way to resolve regulatory and management issues. Option papers, if read and understood by authorities, can also be helpful to the management authority when trying to decide on issues.

In a non-democratic situation, a zoning plan, Reserve regulations, and a management plan should be drafted, in consultation with the management authority, as soon as possible.

5. The circular Reserve boundary should be changed to be rectangular and should run along easily identified latitude and longitude lines. Trying to locate this circular boundary position when at sea during enforcement operations is very difficult. Operationally, a rectangular boundary with easy to identify coordinates is more practical.

6. Mooring and demarcation buoys should be installed to provide vessels with non-destructive mooring facilities and to designate harvest refugia areas.

7. Obtain a 50 foot diesel powered vessel that can be used for research, enforcement, and maintenance work in the Reserve. This vessel will be large enough to handle the weather conditions offshore and will allow research teams to spend extended periods of time in the Reserve in relative comfort. This would be a better alternative than trying to build and maintain an offshore research station in the Reserve that would be subject to hurricane damage. A large vessel will provide more flexibility to Reserve staff and visitors for accomplishing the various missions necessary to manage the area. Efforts should be made to obtain this vessel via donation.

8. CARICOMP coral reef ecosystem monitoring protocols (Smith and Ogden 1993) **should be established and maintained as the backbone of the Reserve monitoring program.** Steps should be taken to join the CARICOMP program and Reserve staff should be trained in CARICOMP monitoring procedures. CARICOMP monitoring is presently being conducted off Great Corn Cay (seaward of Bluefields) in Nicaragua. CARICOMP monitoring sites will be incorporated into the new Global Coral Reef Monitoring Network.

9. Use patterns should be determined so management can understand the cumulative impact to the resource and set realistic carrying capacities. Periodic overflights and fishermen interviews would be the best way to accomplish this.

10. Nicaragua should join the International Coral Reef Initiative (ICRI). USAID should help Nicaragua draft a letter to the ICRI Coordinator, requesting to join ICRI. Being a member of ICRI could help Nicaragua obtain additional grant funds to manage the Reserve.

11. Obtain Biosphere Reserve Status from UNESCO for the Cayos Miskitos Marine Reserve. The main advantage of joining this program is that it certifies the unique and important status of the resource and makes it part of an international network. This in turn can be helpful in obtaining grant funding for Reserve management from the International Man and the Biosphere (MAB) Program and other sources. MAB training opportunities are also available from time to time.

There is no change of ownership or sovereignty by being part of the International Man and the Biosphere Network. Therefore, this designation is not a substitute for Cayos Miskitos Marine Reserve regulations passed by the Nicaraguan government. Fishing can still be done in a biosphere reserve.

The application of the biosphere reserve concept primarily results in the adoption of a cooperative community framework for promoting conservation programs and regional activities. An ecosystem approach to management and sustainability hopefully will be achieved, not through increased legal means and zoning laws, but through open and democratic dialogue, education and community participation.

12. SCUBA diving training capacity should be developed in Puerto Cabezas and other appropriate villages. This could be done through MARENA or on a commercial basis by training a few people interested in setting up a small business. In either case, the goal is to provided some place that offers diver certification training. This will help reduce the number of diving related deaths and injuries to the local population. Since this is a major problem in the Reserve, Reserve regulations could also state that only certified divers are allowed to dive in the Reserve.

ACKNOWLEDGEMENTS

This work was funded by the USAID/NOAA resource services support agreement under contract to Coral Seas Inc. - Integrated Coastal Zone Management as part of the USAID Environmental Initiative of the Americas fisheries project in Nicaragua (Project Coordinator: Dr. Lamarr B. Trott, NOAA, National Marine Fisheries Service). SCJ wishes to thank Stephen D. Cairns, Smithsonian Institution, National Museum of Natural History for assistance in obtaining collecting permits.

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ATOLL RESEARCH BULLETIN

NO. 458

ARE CURRENT ESTIMATES OF CORAL REEF BIODIVERSITY TOO LOW? THE VIEW THROUGH THE WINDOW OF A MICROCOSM

BY

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ISSUED BY
NATIONAL MUSEUM OF NATURAL HISTORY
SMITHSONIAN INSTITUTION
WASHINGTON, D.C., U.S.A.
SEPTEMBER 1998

ARE CURRENT ESTIMATES OF CORAL REEF BIODIVERSITY TOO LOW? THE VIEW THROUGH THE WINDOW OF A MICROCOSM

BY

Allegra M. Small[1], Walter H. Adey[1], and Don Spoon[1]

ABSTRACT

Our results have provided an estimate of the biodiversity of pan tropic coral reefs that is more than 3 times higher than that previously published. The biodiversity of global coral reefs has recently been estimated at approximately 1 million species based on what is currently known about tropical rain forests. However, in order to determine the actual biodiversity of even a single coral reef locality, an extensive team effort on the part of hundreds of specialists would be required. Close examination of the mature 5 m^2 Caribbean coral reef microcosm described in this paper provided 534 species, with an estimated 70% tallied. Using the area/diversity relationship $S=kA^Z$, we were able to more accurately assess the probable biodiversity of wild reefs. This outstanding species biodiversity, based in an extensive range of higher taxa, reconfirms the essential need to restore and conserve one of the most precious ecosystems on earth.

INTRODUCTION

In the middle decades of the 20th century, it was widely accepted by biologists that about one million currently-living species occurred on the planet earth. Grave doubts have been raised in recent decades, primarily based on modern studies in tropical rain forests, that this number is even remotely close to reality. Indeed 10 million is currently a low estimate with some scientists citing 30-100 million species (Wilson and Peter, 1988; Ehrlich and Wilson, 1991; Wilson, 1992; Stork, 1993; Lovejoy, 1997).

While coral reef biologists have long known that tropical reefs are rich in species, no serious effort has been made to actually "dissect" a well-developed reef ecosystem to determine a realistic biodiversity number. In truth, a thorough study would be extraordinarily difficult and would require a team effort by hundreds of specialists. A recent analysis of what is known about coral reef biodiversity (93,000 identified species) and what can be estimated about actual biodiversity (950,000 predicted species) has been carried out by Reaka-Kudla (1997). We quote the key elements of Reaka-Kudla's conclusions:

> "These analyses suggest that about 93,000 total described species of all taxa occur on coral reefs, which represents about 5% of the described global biota. These numbers are considerably lower than the number of species that are

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Manuscript received 1 July 1998; revised 18 August 1998

> estimated to occur in rain forests. However, coral reefs occupy only 5% of the global area of rain forests. If coral reefs were equivalently studied and contained as much biodiversity as rain forests per km^2, and if rain forests contained 2 million species, then coral reefs should include approximately 950,000 species. The difference between the numbers of described (93,000) versus expected (950,000) species suggests that coral reefs are repositories of very high undocumented species diversity. Most species on coral reefs are relatively small and cryptic, and difficult to observe and collect. This, in combination with the fact that tropical environments and particularly tropical marine habitats receive less study than those of higher latitudes or terrestrial sites, suggests that many coral reef taxa are indeed very poorly known."

Adey (1983) suggested that microcosms of coral reefs could be utilized to better understand the function of these extremely complex ecosystems. Although this approach has not been widely utilized by researchers, more recently, the microcosm described herein has been employed effectively as a tool to better understand reef metabolism, specifically the process of calcification and its relationship to photosynthesis (Small and Adey, in manuscript). As that study has demonstrated, properly constructed microcosms have the ability to maintain a natural reef's physical, chemical and biological characteristics for many years; thus microcosms have the capability to be used as tools in the first approaches to solving many extremely difficult problems, such as the magnitude of biodiversity, the nature of community structure and their controlling factors. The larger, and generally far more remote, reef ecosystems of tropical seas can then be approached *in situ* to test the hypotheses already developed and tested at a more manageable and controllable laboratory scale.

In this paper we present the results of a year-long study of the biodiversity of a mature coral reef microcosm used primarily for metabolism and calcification research. Except for specific, macro species additions for research, amounting to less than 5% of the total flora and fauna, the biota of this system was taken in two distinct collections made in 1983 and 1991 at a single coral reef locality in the tropical West Atlantic. This represents what could be termed two sets of samples from a single habitat (and is therefore a sample of alpha diversity), while the only sufficient comparison that is available is an estimate of gamma or regional reef diversity taken from multiple samples (i.e. many thousands) over long periods of time.

As we describe in this paper, the extraordinary diversity found in this microcosm, based on minimal collections from a single locality in the Tropical Western Atlantic, suggest a considerably larger diversity in tropical reefs than that described above.

MATERIALS & METHODS

The biodiversity of a Caribbean coral reef microcosm, which has been functioning without significant biological input for over 7 years, was determined (Figure 1). Originally set up in 1988, the microcosm is a 400 liter system with a 1,280 liter refugia, and was

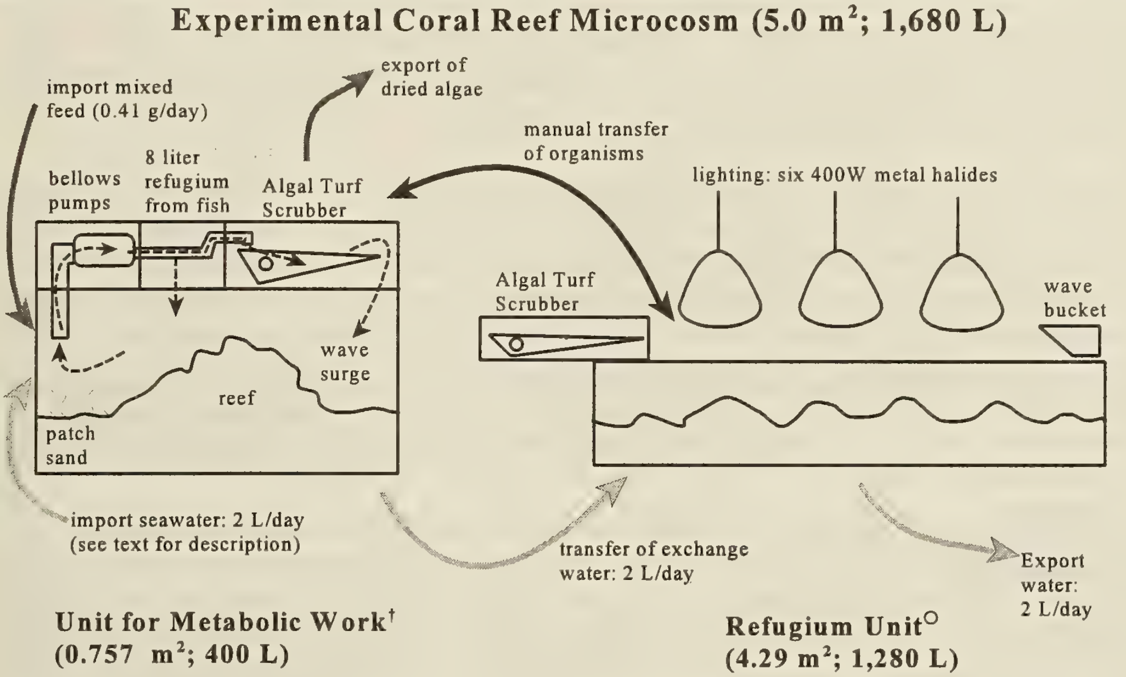
Experimental Coral Reef Microcosm (5.0 m²; 1,680 L)
import mixed feed (0.41 g/day)
export of dried algae
manual transfer of organisms
8 liter refugium from fish
bellows pumps
Algal Turf Scrubber
lighting: six 400W metal halides
Algal Turf Scrubber
wave bucket
wave surge
reef
patch sand
import seawater: 2 L/day (see text for description)
transfer of exchange water: 2 L/day
Export water: 2 L/day
Unit for Metabolic Work†
(0.757 m²; 400 L)
Refugium Unit○
(4.29 m²; 1,280 L)

Figure 1. Diagram of the microcosm. Please note the volume of this system is an estimation based on original tank volume minus the estimated volume of the carbonate structure to obtain a water volume. †Lights not shown; See Adey and Loveland (1998) for a detailed mechanical description of this unit. ○Note impeller pumps, (not shown) deliver water from the right hand end of the refugium unit to the Algal Turf Scrubber and the left side of the refugium unit to the wave bucket.

physically and metabolically modeled after the reefs of St. Croix where adequate data were available (e.g. Adey and Steneck, 1985). Significant biological/ecological collections were made from Mayaguana, in the Bahamas, with the last collection occurring in 1991. Refer to Luckett et al (1996) and Adey & Loveland (1998) for detailed information on construction, microcosm set up, daily maintenance, lighting, pumps, refugia, and algal turf scrubber technology (used to match water chemistry with long and short term conditions on the St. Croix reef). The physical and chemical components of the microcosm and the methods used for collection and identification of its species are discussed below.

Physical and Chemical Components of the Microcosm

Small and Adey (in manuscript) determined the physical and chemical components of the microcosm to closely match those of St. Croix (Table 1). The yearly mean total of daily radiation was determined with a pyranograph to be 220 Langleys (cal./cm^2). The light levels of the St. Croix fore-reef are approximately 220 Langleys at a depth of 5 meters (Kirk, 1983; Adey and Steneck, 1985), therefore the physical and chemical components of the microcosm were compared to the St. Croix fore-reef (see Table 1 and Adey and Steneck, 1985). During the period of research, the microcosm ranged from 0.21 to 0.71 μM N-NO_2 + NO_3 (with a mean at 0.56 μM; n=6) as compared to 0.35 to 1.05 μM N-NO_2 + NO_3 at St. Croix (based on a skewed distribution of data points where the most data points occurred at 0.35 μM and the points trailed up to 1.05 μM; Adey and Loveland, 1998).

Table 1. Modified from Small and Adey (in manuscript). Comparisons between microcosm and St. Croix reefs (annual mean or mean daily range with standard error). The St. Croix data is from Adey and Steneck (1985). *indicates the data represents tropical Atlantic means from Millero & Sohn (1992); no data available for St. Croix. **indicates the data represents tropical Atlantic means from Sverdrup et al (1942); no data available for St. Croix. ***indicates data represents tropical world wide means (Pichon, 1995); no direct data for St. Croix at this depth.

	Microcosm	**St. Croix Reefs (fore reef)**
Temperature (°C) (am - pm)	26.5 ± 0.03 (n=365) - 27.4 ± 0.02 (n=362)	24.0-28.5
Salinities (ppt)	35.8 ± 0.02 (n=365)	35.5*
pH (am - pm)	7.96 ± 0.01 (n=62) - 8.29 ± 0.02 (n=39)	no am-pm pH data available for St. Croix reefs; however, pH range is similar based on extensive O_2 data.
Oxygen concentration (mg/l) (am - pm)	5.7 ± 0.1 (n=14) - 8.7 ± 0.2 (n=11)	5.8 - 8.5
GPP (g O_2/m^2/day)	14.2 ± 1.0 (n=4)	15.7
Daytime NPP (g O_2/m^2/day)	7.3 ± 0.3 (n=4)	8.9
Respiration (g O_2/m^2/hr)	0.49 ± 0.04 (n=4)	0.7
N - NO_2^- + NO_3^2 (μmol)	0.56 ± 0.07 (n=6)	0.28
Calcium (mg/l)	491 ± 6 (n=33)	417.2**
Alkalinity (meq/l)	2.88 ± 0.04 (n=59)	2.47*
Calcification (kg/m^2/yr $CaCO_3$) (based on alkalinity depletion - based on calcium input)	4.0 ± 0.2 (n=11) - 4.4 ± 0.1 (n=365)	1-2% of a reef will calcify at 10 kg/m^2/yr, 2-4% at 4 kg/m^2/yr, and 90-95% at 0.8 kg/m^2/yr ***
Light (Langleys/day)	220	430 (surface) 220 (5 meters deep in fore-reef)

The minor variations between the microcosm, as described, and the physical and chemical components of the natural reef are attributed to the maintenance of an enclosed ecosystem separated from the strong open ocean water input characteristic of these reefs.

Without a constant supply of open ocean water, the primary elements of variation (calcium concentrations and alkalinity) continually fall during the day due to calcification, but remain stable at night (Small and Adey, in manuscript). It was therefore necessary to maintain the concentrations of these elements by daily addition of calcium and bicarbonate. In an effort to keep the calcium and bicarbonate in the microcosm from depleting below normal tropical oceanic levels after a full day of calcification, the mean concentrations were maintained at 491 ± 6 mg/l (n=33) and 2.88 ± 0.04 meq/l (n=59), respectively. These elevated levels of calcium and bicarbonate did not significantly effect the calcification rate as demonstrated by student's t-test (Small and Adey, in manuscript). Though the calcification rate of the microcosm ecosystem is 4.0 ± 0.2 kg $CaCO_3/m^2$/year (n=11; based on alkalinity depletion) to 4.4 ± 0.1 kg $CaCO_3/m^2$/year (n=365; based on calcium input), individual coral colonies are calcifying at rates as high as 20 kg $CaCO_3/m^2$/year (e.g. *Acropora sp.*) (see Small and Adey, in manuscript, for rates of all microcosm components).

The gross primary productivity (GPP) of the microcosm (14.2 ± 1.0 g O_2/m^2/day; n=4) is higher than the world-wide averages for tropical reefs (10 g O_2/m^2/day) (Crossland et al, 1991). However, it is 1.5 g O_2/m^2/day lower than that determined for the St. Croix fore-reef by Adey and Steneck (1985). These differences in the mean GPP of the microcosm and St. Croix can be explained by the differences in spatial heterogeneity. Because of the much smaller area of the enclosed microcosm, spatial heterogeneity cannot be developed at levels equivalent to the very high spatial heterogeneity of the well-developed Caribbean fore-reef.

Collection and Identification Procedures

Original Collections

The vast majority of the organisms present in the microcosm came from two original collections on the southwest reef of Mayaguana. Both of the collections were part of larger collections made for an exhibit microcosm in the Smithsonian Institution's Natural History Museum. These collections were mini-ecosystem collections of 50-70, 0.03 m^3 units (lugs), which contained live-sand, live-rock, specific macro-invertebrates, algae and fish. The first collection occurred as several sub-collections from 1980-1983, and was flown in coolers by plane directly to the larger exhibit microcosm at the Smithsonian, and maintained there until 1988 when a small portion was then transferred to establish the microcosm described in this paper. The primary collection (1991) was transported by research vessel with ocean flow-through capability from the Bahamas, up the Gulf Stream to Cape Hatteras. At Cape Hatteras, the collection systems were converted to on board algal turf scrubber control (Adey and Loveland, 1998) for about 24 hours until arrival at the microcosm system on the shore of the Chesapeake Bay. It was from this larger collection that sub-samples were taken to provide the majority of the microcosm ecosystem. The remainder of the collection was then transferred to a rebuilt exhibit microcosm at the Smithsonian.

In addition to the species from the Mayaguana collections, a few Indo-Pacific species were introduced within the first years of operation (i.e. giant clams, soft corals, fish). These species were bought as individuals, with little possibility of accidentally introducing other organisms. More recently, fish have occasionally been replaced when necessary (as they were lost by internal predation). Finally, in 1996, two species of Indo-Pacific stony coral (*Acropora sp.* and *Montipora digitata*) mounted on plastic holders at Inland Aquatics inTerre Haute, IN (and therefore without other species on their bases) were added for determination of calcification rates (Small and Adey, in manuscript). The only possible source of unknown organism introduction would be through the addition of Chesapeake Bay water that was exchanged in small amounts daily (2 L). In order to reduce the introduction of larvae and microorganisms in the water, the Bay water (~ 18 ppt) was increased in salinity by the addition of aquarium salts to ~50 ppt, and then brought back down with distilled water to normal tropical oceanic concentrations (~35 ppt), over a few days time in a dark holding reservoir. The analysis of the microorganisms present in the Chesapeake Bay, the holding reservoir, and microcosm showed only four possible species that might have been introduced to the microcosm using this technique. These cosmopolitan species occur naturally in brackish and fully saline waters.

With exception of the few selective introductions mentioned above, there has been no significant input of organisms into the microcosm for 7 years. The vast majority of species found in the microcosm today have been maintaining viable populations through reproduction.

Collection of Organisms for Identification

Organisms were identified whenever possible without removal from the microcosm. This was only possible for about 10% of the total species found. To minimize disturbance of the 400 liter portion of the microcosm, only those organisms that could be identified without removal or with minimal disturbance of the entire system, were identified. The much larger refugium allowed for live-rock and sand samples to be taken without impacting the ecosystem. Sand was sieved for removal of larger organisms and the remaining sand was sorted through under a dissecting microscope. Small pieces of live-rock were also placed under the dissecting microscope for locating species on the surface. Larger pieces of live-rock were broken open to reveal species hidden inside. Representative samples of live-rock and sand were taken from different areas and depths within the microcosm.

The majority of macro species were able to be identified by being placed live under the dissecting microscope. These organisms were returned to the system after the identifications were made. Many of the smaller invertebrates were collected and fixed for identification. Arthropods and sponges were fixed and preserved in 70% ethyl alcohol. Polychaete worms were narcotized with 7.5% $MgCl_2$ in seawater, fixed in 10% formalin, and preserved in 70% ethyl alcohol. Sipunculids were relaxed in 7% $MgCl_2$ in freshwater, fixed in 10% formalin, and preserved in 70% ethyl alcohol. Except for about twenty larger species collected individually by hand or forceps, the algae were taken as samples of substrate, teased apart under a dissecting microscope and identified under the compound microscope. A Scanning Electron Microscope (SEM) was used in the identification of diatoms.

Microorganisms were collected and identified alive using an array of techniques. For artificial substrates, inverted 50 mm plastic petri dishes inserted into Styrofoam cup sections were placed on the water's surface (Spoon and Burbanck, 1967), and glass slides with glass coverslips (affixed with thin strips of 50 μm thick Adcom™ double sticky tape) were inserted vertically into the sediment creating horizontal chambers at different depths. Microcompression chambers for detritus samples were created on glass slides by using thin plastic Handiwrap™ film as a gas exchanging coverslip (attached peripherally with Dow Corning™ silicone stopcock grease), which allowed for living preparations to last many hours (Spoon, 1976). In addition, plankton samples were collected by filtering water through 100 μm and 20 μm meshes.

Identifications

The major taxonomic groupings of organisms were divided amongst the authors for identification. Walter Adey was responsible for the algae, including diatoms but excluding dinoflagellates, Allegra Small was responsible for the macroscopic animals, and Don Spoon for the protozoa, dinoflagellata and micrometazoa. Due to high diversity of the macroscopic invertebrates and the difficulty in identification of a great number of species, the majority of invertebrates were identified only to family level and then sent to the appropriate specialist for further identification. Table 2 lists the assisting specialists and their taxonomic group of expertise. For organization at higher taxonomic level, Parker et al (1982) was used as a guideline, except in the case of the Protists, in which (Corliss, 1994) was used.

Approximately one year of roughly one-third time was spent in this collecting/identifying endeavor. Another year of similar time would have been required to nearly complete the tally, and several additional specialists would have been required (nematodes, fungi, bacteria, viruses, parasitic genera and the minor phyla not yet explored). It is our mutual judgement that approximately 30% of species in the system remain uncounted, not including bacteria, viruses and parasites, which would likely add an order of magnitude to the species count. Since bacteria, viruses and parasites are not usually considered in biodiversity estimates, we do not consider them in our calculations for coral reef biodiversity. With increasing intensity of examination of the microcosm, special precautions would have to be taken to avoid altering the ecosystem through collection procedures.

RESULTS

The results of the species collections and identifications are listed in Appendix A. A total of 534 species were found at last count, with several phyla not considered, and approximately 30% of species unaccounted for. At higher taxonomic level, distribution of species number is approximately 25% algae, 45% invertebrates, 30% Protozoa and lower Metazoa, and only a few chordates. These percentages are referring to the number of species in each grouping, not the abundance. Abundances of each species were difficult to estimate with any level of accuracy due to the destructive sampling techniques required to do so. The higher taxonomic diversity, with the 534 species spanning 96 orders and 27 phyla, makes this coral reef microcosm a truly diverse ecosystem.

Table 2. Specialists consulted for the identification of invertebrates.

Taxonomic Group	**Identifying Specialist**
Subclass Ostracoda	Richard Benson, Smithsonian Institution Louis Kornicker, Smithsonian Institution
Order Tanaidacea	Richard Heard, Gulf Coast Research Laboratory
Subclass Copepoda	Rony Huys, The Natural History Museum, London Sophie Conroy-Dalton, The Natural History Museum, London Chad Walter, Smithsonian Institution
Order Isopoda	Marilyn Schotte, Smithsonian Institution
Order Amphipoda	Sara LeCroy, Gulf Coast Research Laboratory
Class Granuloreticulosea (Foraminifera)	Beth Burkhard, independent contractor, beth@intrepid.net, (collected and identified specimens)
Phylum Mollusca	Raye Germon, Smithsonian Institution
Phylum Nemertea	Jon Norenburg, Smithsonian Institution
Phylum Porifera	Klaus Ruetzler, Smithsonian Institution
Phylum Sipuncula	Mary Rice, Smithsonian Institution Julie Piraino, Smithsonian Institution
Family Terebellidae	Pat Hutchings, The Australian Museum
Family Maldanidae	Andrew Mackie, National Museum of Wales
Family Syllidae	Guillermo San Martin, Universidad Autonoma de Madrid
Family Spirorbidae	Wyn Knight-Jones, University of Wales
Family Cirratulidae	James Blake, ENSR Consulting and Engineering, Inc.
Family Serpulidae	Harry A. ten Hove, Zoological Museum, Amsterdam
Family Sabellida	Kirk Fitzhugh, Los Angeles County Museum of Natural History
Order Eunicida, Families Orbiniidae, Paraonidae, Ctenodriliae, Capitellidae, Oweniidae	Kristian Fauchald, Smithsonian Institution

Using the standard relationship between species diversity and area ($S=kA^Z$) that has been utilized since the 1960's for relating biodiversity to area, and more recently used by Wilson (1992), May (1994) and Reaka-Kudla (1997), it is possible to estimate the total number of species that should appear in natural coral reefs worldwide based on this microcosm. The first step is to determine, based on our diversity of a 5.0 m^2 Caribbean coral reef microcosm, the estimated diversity of the Caribbean reefs. To do this the Z value of 0.25 (Reaka-Kudla, 1997) and the Caribbean coral reef area as determined by Spalding and Grenfell (1997) ($A=23 \times 10^9$ m^2) was used. Note that the value of the constant (k) will be the same for the microcosm and natural reefs, so it can be canceled out on both sides of the equation. The calculations for the first step are as follows:

S_1=predicted Caribbean reef diversity; S_2=diversity of the microcosm (532, without bacteria); A_1=area Caribbean reefs; A_2=area microcosm; $Z=0.25$

$$k=\frac{S_1}{A_1^Z}=\frac{S_2}{A_2^Z} \qquad S_1=\frac{(S_2)(A_1^Z)}{A_2^Z} \qquad S_1=\frac{(532)(23x10^9)^{0.25}}{(5.0^{0.25})}=138{,}394$$

With the diversity of Caribbean reefs at about 1/12th of that of pan tropic coral reefs (based on Paulay, 1997), and with the estimated Caribbean reef diversity of approximately 138,000, it can be further interpolated that the pan tropic reefs have a diversity of 1,656,000 species. These diversity numbers for the Caribbean and pan tropic coral reefs are a bare minimum. Considering that the actual diversity of the 5.0 m^2 microcosm is more likely to be 30% higher than determined (due to the estimated number of species not yet found and the various phyla not considered), the Caribbean and pan tropic reef diversities can be recalculated to be:

$$S_1=\frac{(692)(23x10^9)^{0.25}}{(5.0^{0.25})}=$$ 180,217 for the Caribbean and 2,162,603 pan tropic.

In addition, the microcosm has been running for 7 years without significant introduction of species. It can be safely assumed that many species were not represented in the original collections, and that additionally some did not survive either translocation, 7 years of life in the microcosm, or were not able to reproduce due to lack of a mate or for other reasons. Conservatively estimating the number of species that did not survive the extended period of time in the microcosm to be approximately 20 ± 10%, we can once again recalculate the predicted diversity of Caribbean and pan tropic reefs to be:

$$S_1=\frac{(830)(23x10^9)^{0.25}}{(5.0^{0.25})}=$$ 216,156 for the Caribbean and 2,593,874 pan tropic.

The difference between this estimated 2.6 million species pan tropic and the previously published estimate of 950,000 species (Reaka-Kudla, 1997) is even greater when considering the differences in coral reef areas used for the respective calculations. Reaka-Kudla used a pan tropic coral reef area of 6.0×10^{11} m^2 for her calculations (a commonly used estimate of reef area; Smith, 1978). For our calculations, we used the more conservative and recent coral reef area estimates of Spalding and Grenfell (1997), 23×10^9 m^2 for Caribbean reefs, and 2.6×10^{11} m^2 pan tropic. For comparison to Reaka-Kudla's numbers, our estimated biodiversity can be further adjusted, using the less conservative area of 6.0×10^{11} m^2 and the formula above, to be approximately 3.2 million species pan tropic. Though the actual current area of worldwide reefs may be debatable, our numbers show that the biodiversity of pan tropic reefs to be more than 3 times what has been previously estimated.

DISCUSSION

The $S=kA^Z$ relationship is basically empirical. Whether it adequately states the difference between alpha (habitat) and gamma (regional) diversity, with the equation allowing for the increase in habitats with greater area, or whether there are significant additional factors probably doesn't matter to its use in this context. What probably does matter is that the relationship was developed largely for vertebrates in island terrestrial communities. It certainly has not been adequately tested for marine ecosystems and especially very high diversity ecosystems. Accepting that this relationship is all we have to work with in this context, and it is widely used, our primary concern for the use of the coral reef microcosm for estimating natural reef diversity is whether or not the Mayaguana reef habitat was adequately sampled.

As was shown by Small et al (1996), for relatively simple stream systems with a macrophyte species count of 30-60 species, at least 10 samples considerably larger (~5 m^2) than that employed here were required to approach local ecosystem diversity. In this case, only a limited taxonomic group was being considered. Gage and Tyler (1991) describe the similar rarefaction technique used in sampling deep sea soft bottom fauna. In one case cited, 168, 0.1 m^2 box cores failed to produce a rarefaction curve that approached the asymptote - or in other terms, 25 species were still being discovered as each m^2 of sample was added, at the limit of the curve. This kind of information is not yet available for coral reef ecosystems. However, it seems reasonable to state that the sampling employed in the collecting process of this investigation (smaller sub-samples of the approximately 120, 0.03 m^3 samples taken at two separate times) could not begin to sample adequately the total biodiversity of the Mayaguana reef. Thus, the samples returned to the microcosm for community and ecosystem development must have considerably understated the actual diversity of the Mayaguana reef.

Although considerable efforts were taken to avoid species loss in transit, certainly some especially larger species were lost in transit or in the process of establishment in the new habitat. Even in newly available wild habitat, a considerable period of time is required to build up to typical species densities. Thus, as large as the species density is in this relatively small microcosm, it almost certainly understates coral reef diversity *in situ*.

Though the microcosm has an inter-reef refugium to aid in larval development outside of predation, it lacks the essential open ocean refuge for those species that live and breed on coral reefs but spend their larval phases in open water where predation is considerably less marked. Many fish species are in this category and spend weeks to months in open ocean plankton. Indeed, coral reef fish often reproduce in microcosms but the larvae do not successfully recruit to the reef unless specific steps are taken to protect them from predation and provide appropriate plankton for feed (this has been accomplished for about two dozen fish species; e.g. Adey and Loveland, 1998). Fish constitute less than 1% of coral reef species and this failure to generally maintain populations would make little direct difference to our overall diversity analysis. However, other invertebrate groups probably also fall into this category and thus would be a missing element in the microcosm. It should be emphasized that this particular microcosm, in part operates with bellows (rather than impeller) pumps and thus, at least in the 400 L section, planktonic stages could theoretically last indefinitely in the water column (and some clearly do so). However, this does not solve the predation issue as it relates to those many species that require an open ocean refugium.

Reaka-Kudla based her calculations on the assumption that tropical rain forests contain 2 million species. She acknowledges that this is a conservative estimate, and predicts that if tropical rainforests contain more species, in turn coral reefs could contain more species. Based on a tropical rainforest diversity of 2 million species and what we now know to be the current estimate of coral reef diversity (2.6 - 3.2 million species, depending on the true area of coral reefs), coral reefs have a much higher species/area density than rainforests. Otherwise, if it is indeed true that coral reefs have the same species/area density of rainforests, than the current estimate of tropical rainforest biodiversity used by Reaka-Kudla (1997) is much too low.

CONCLUSION

Based on the 5.0 m^2 Caribbean coral reef microcosm described in this paper, and the species/area relationship $S=kA^Z$, pan tropic coral reef biodiversity can be conservatively estimated to be approximately 3 million species. While major field efforts and continued microcosm development work is necessary to develop more acceptable numbers, this new estimate shows that the previous estimate of pan tropic coral reef biodiversity developed by Reaka-Kudla (1997) is most certainly low. Whether actual numbers are only three times as much as Reaka-Kudla's estimate or an order of magnitude higher cannot be stated at this time. The importance of coral reef biodiversity can be further recognized when considering that coral reefs have a much higher diversity at higher taxonomic levels than tropical rain forests (Paulay, 1997). As most probably the ecosystem with the highest specific diversity (species per unit area) in the biosphere, each day's decline of coral reefs is a devastating loss to the human race. This concern need not be framed only in esthetic or local concerns. As coral reefs likely bear the highest specific diversity of yet unknown biochemicals, the ongoing loss of reefs is providing considerable loss of potential to the human pharmacopoeia. The clear concern by many scientists for the loss of these very rich ecosystems, before we even understand just how rich they are, is very real (Paulay, 1997; Reaka-Kudla, 1997; Adey, 1998).

ACKNOWLEDGMENTS

As noted in Table 2, numerous specialists assisted our work in providing or confirming species and generic identifications. Without their expertise and time expenditure, this study would have far less value to furthering our understanding of coral reef ecosystems. The microcosm described in this paper has been operating for many years and the authors could not always be present to provide maintenance. Many Marine Systems Laboratory employees and trained volunteers, too numerous to cite individually, and friends assisted in this effort. Finally, and most importantly, we are grateful for the financial and moral support of Rampa Hormel. Rampa wanted to support coral reef conservation, and we sincerely hope that our work (this is the first of a series of papers resulting from her assistance) will directly or indirectly lead to a more significant effort to conserve coral reefs.

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Appendix A. Species list for the 5 m^2 coral reef microcosm. * = pacific species. Total: 534 species, 357 genera, 241 families, 96 orders (with suborders), 44 classes (with subclasses, 27 phyla (+2 subphyla), 4 kingdoms (+3 subkingdoms). Note: bacteria and nematodes are listed only where identification was possible without a specialist. An investigation of fungi, viruses, primarily parasitic genera and the minor phyla Prochlorophyta, Gnathostomulida, Mesozoa, Kinorhyncha, Entoprocta, Phoronida and Echiura not yet initiated, and would provide numerous additional species.

SUPERKINGDOM PROKARYOTAE
KINGDOM MONERA

DIVISION BACTERIA
- **O. Cytophagales**
  - F. Cytophagaceae
    - *Cytophaga sp.*
  - F. Beggiatoaceae
    - *Beggiatoa sp.*

DIVISION CYANOPHYCOTA
(Blue-Green Algae)
- C. CYANOPHYCEAE
  - **O. Chroococcales**
    - F. Chroococcaceae
      - *Microcystis aeruginosa*
      - *Microcystis montana*
      - *3 Microcystis spp.*
      - *Gomphosphaeria aponina*
      - *Johannesbaptista pellucida*
  - **O. Pleurocapsales**
    - F. Pleurocapsaceae
      - *4 Pleurocapsa spp.?*
      - *"Aplastidallies nsp."*
    - F. (new families being described)
      - *"Amoebabacter nsp."*
      - *"Axiobacter nsp."*
      - *"Nothrobacter megalum" nsp.*
      - *"Nothrobacter nsp."*
  - **O. Nostocales**
    - F. Oscillatoriaceae
      - *Porphyrosipho leurzii*
      - *Schizothrix mexicana*
      - *Schizothrix calcicola*
      - *Microcoleus lyngbyaceae*
      - *Oscillatoria lutea*
      - *Arthrospira sp.*
      - *Spirulina subsalsa*
      - *Spirulina major*
    - F. Rivulariaceae
      - *Calothrix crustacea*
      - *3 Calothrix spp.*
    - F. Scytonemataceae
      - *Scytonema hofmannii*

SUPERKINGDOM EUKARYOTAE
KINGDOM PLANTAE

PHYLUM RHODOPHYCOTA
(Red Algae)
- C. RHODOPHYCEAE
- S.C. BANGIOPHYCIDEAE
  - **O. Porphyridiales**
    - F. Goniotrichaceae
      - *Goniotrichum alcidii*
      - *Erythrotrichia carnii*
- S.C.FLORIDEOPHYCIDEAE
  - **O. Nemalionales**
    - F. Acrochaetiaceae
      - *Acrochaetium sagraenum*
      - *Rhodochortin corynosporoides*
    - F. Gelidiaceae
      - *Gelidium pusillum*
    - F. Wurdemanniaceae
      - *Wurdemannia miniata*
  - **O. Cryptonemiales**
    - F. Peyssonneliaceae
      - *Peyssonnelia sp.*
      - several unidentified spp.
    - F. Corallinaceae
      - *Mesophyllum mesomorphum*
      - *Lithothamnium ruptile*
      - *Sporolithon sp.*
      - *Neogoniolithon mammilarum*
      - *2-3 Neogoniolithon spp.*
      - *Lithoporella atlantica*
      - *Heteroderma farinosa*
      - *Jania capillacea*
      - *Amphiroa fragillissima*
  - **O. Gigartinales**
    - F. Hypneaceae
      - *Hypnea spinella*
  - **O. Rhodymeniales**
    - F. Rhodymeniaceae
      - *Fauchea peltata*
      - *Botryocladia occidentalis*
      - *Botryocladia pyriformis*
    - F. Champiaceae
      - *Coelothrix irregularis*
  - **O. Ceramiales**
    - F. Ceramiaceae
      - *Callithamnion balliae*
      - *Centroceras clavulatum*
      - *Spyridia filamentosa*
    - F. Delesseriaceae
      - *Hypoglossum tenuifolium*
    - F. Rhodomelaceae
      - *Polysiphonia subtillissima*

Herposiphonia secunda
Lophosiphonia cristata
Acanthophora spicifera
Laurencia microcladia
Laurencia corallopsis
Chondria dasyphylla

PHYLUM CHROMOPHYCOTA
C. CRYPTOPHYCEAE
O. Cryptomonadales
F. Cryptomonadaceae
Cryptomonas sp.
Chilomonas sp.
C. BACILLARIOPHYCEAE (Diatoms)
O. Centrales
F. Hemidiscaceae
Actinocyclus sp.
O. Pennales
S.O. Araphidineae
F. Diatomaceae
Microtabella sp.
3 Licmophora sp.
Neosynedra sp.
Catacombas sp.
S.O. Biraphidineae
F. Naviculaceae
Seminavis sp.
Proschkinia sp.
4 Pleurosigma sp.
Gyrosigma sp.
Fallacea sp.
Diploneis sp.
F. Cymbellacea
3 Amphora spp.
F. Entomoneidaceae
Entamoneis sp.
F. Nitzschiaceae
3 Nitzschia spp.
Bacillaria sp.
Hantzschia sp.
Denticula sp.
F. Epithemiaceae
3 Rhopalodia spp.
F. Mastogloiaceae
Mastogloia sp.
S.O. Monorhaphidineae
F. Achnanthaceae
6 Cocconeis spp.
2 Acanthidium spp.
Anorthoneis sp.
C. DINOPHYCEAE (Dinoflagellates)
O. Gymnodiniales
F. Gymnodiniaceae
Amphidinium sp.
Gyrodinium sp.
2 Gymnodinium sp.
2 unidentified spp.
O. Peridinales
F. Gonyaulacaceae
Gonyaulax sp.
O. Prorocentrales
F. Prorocentraceae
2 Prorocentrum sp.
O. Zooxanthellales
F. Zooxanthellaceae
Zooxanthella microadriatica
C. PHAEOPHYCEAE (Brown Algae)
O. Ectocarpales
F. Ectocarpaceae
Giffordia mitchellae
Herponema tortugensis

PHYLUM CHLOROPHYCOTA (Green Algae)
C. CHLOROPHYCEAE
O. Ulvales
F. Ulvaceae
Enteromorpha compressa
O. Cladophorales
F. Cladophoraceae
Chaetomorpha linum
Cladophora crispula
Cladophora crystallina
Cladophora delicatula
O. Siphonales
F. Valoniaceae
Valonia aegagrophila
Dictyosphaeria ocellata
O. Bryopsidales
F. Derbesiaceae
Derbesia vaucherieformis
Derbesia lamarouxii
Derbesia marina
F. Caulerpaceae
Caulerpa taxifolia
Caulerpa mexicana
Caulerpa sertularioides
F. Codiaceae
Avrainvillea asarifolia
Avrainvillea longicaulis
Avrainvillea nigricians
Halimeda opuntia
Halimeda tuna
Halimeda incrassata
O. Coleochaetales
F. Coleochaetaceae
Coleochaete sp.

PHYLUM MAGNOLIOPHYTA
C. LILIOPSIDA
O. Hydrocharitales
F. Hydrocharitaceae
Thalassia testudinum

KINGDOM PROTISTA

PHYLUM PERCOLOZOA
C. HETEROLOBOSEA
O. Schizopyrenida
F. (new family being described)
"Bactoamoeba nsp."
Euhyperamoeba sp.
F. Vahlkampfiidae
2 Vahlkampfia spp.
C. PSEUDOCILIATA
F. Stephanopogonidae
Stephanopogon corona

Stephanopogon mobilensis

PHYLUM EUGLENOZOA
C. EUGLENOIDEA
O. Euglenida
S.O. Eutreptina
Eutreptia sp.
S.O. Heteronematina
Peranema sp.
Perinemopsis sp.
1 unidentified sp.
C. KINETOPLASTIDEA
O. Bodonida
S.O. Bodonina
F. Bondonidae
Bodo saltans
6 Bodo spp.

PHYLUM CHOANOZOA
C. CHOANOFLAGELLATA
O. Choanoflagellata
F. Codosigidae
Codosiga sp.
Monosiga sp.?
F. Salpingoecidae
Salpingoeca sp.

PHYLUM RHIZOPODA
C. LOBOSEA
F. Acanthamoebidae
Acanthamoeba gigantea
F. Hartmannellidae
Hartmannella sp.
F. Hyalodiscidae
Hyalodiscus sp.
F. Mayorellidae
Mayorella sp.
Vexillifera sp.
F. Reticulosidae
2 Penardia spp.
F. Saccamoebidae
Saccamoeba fulvum
F. Thecamoebidae
Thecamoeba sp.
F. Trichosphaeridae
Trichosphaerium platyxyrum
C. FILOSEA
F. Vampyrellidae
Nuclearia sp.
C.GRANULORETICULOSEA
(Foraminifera)
F. Allogromiidae
2 Allogromia spp.
F. Ammodiscidae
Ammodiscus sp.
F. Astrorhizidae
Halyphysema sp.
F. Ataxophragmiidae
Clavulina cf. tricarinata
F. Bolivinitidae
Bolivina cf. paula
2 Bolivina spp.
F. Cibicidiidae
Cibicides sp.
F. Cymbaloporidae
Cymbaloporetta squamosa
F. Discorbidae
Discorbis rosea
Discorbis sp.
3 Rosalina spp.
F. Homotremidae
Homotrema rubrum
F. Peneroplidae
Laevipeneroplis protea
F. Miliolidae
8 Quinqueloculina spp.
Triloculina oblonga
Triloculina sp.
F. Planorbulinidae
Gypsina sp.
Planorbulina cf. acervalis
F. Siphoninidae
Siphonina cf. clairbornensis
F. Soritidae
Archais angulatus
Cyclorbiculina compressa
Peneroplis pertusus
Sorites orbicula
F. Textulariidae
Textularia cf. conica

PHYLUM CILIOPHORA
C. KARYORELICTEA
F. Kentrophoridae
Kentrophorus flavum
C. POLYHYMENOPHOREA
S.C. HETEROTRICHIA
F. Blepharismidae
Anigsteinia clasissimum
Parablepharisma sp.
F. Condylostomatidae
Condylostoma sp.
F. Folliculinidae
Folliculina sp.
Magnifolliculina sp.
Metafolliculina sp.
Parafolliculina sp.
F. Peritromidae
2 Peritromus spp.
F. Protocruziidae
2 Protocruzia spp.
S.C. SPIROTRICHIA
F. Aspidiscidae
Aspidisca aculeata
6 Aspidisca spp.
F. Chaetospiridae
Chaetospira sp.
F. Discocephalidae
Psammocephalus sp.
F. Euplotidae
Certesia quadrinulceatum
Diophrys appendiculatus
Diophrys histrix
Diophrys irmgard
Diophrys scutum
Euplotes crassus
5 Euplotes spp.
F. Keronidae
2 Epiclintis spp.
Keronopsis rubra
4 Keronopsis spp.

F. Oxytrichidae
Tachysoma sp.
F. Psilotrichidae
Kiitricha marina
F. Ptycocyclidae
2 Favella spp.
F. Spirofilidae
Stichotricha simplex
F. Strombidiiae
Strombidium sp.
F. Uronychiidae
Uronychia trasfuga
Uronychia sp.
F. Urostylidae
2 Holosticha spp.
Uroleptus sp.
Urostyla sp.
C.OLIGOHYMENOPHOREA
S.C. SCUTICOCILIATA
F. Cinetochilidae
Cinetochilum marinum
F. Cyclidiidae
3 Cyclidium spp.
F. Pleuronematidae
3 Pleuronema spp.
F. Uronematidae
Uronema filicicum
S.C. PERITRICHA
F. Vaginicolidae
Cothurnia sp.
F. Vorticellidae
Vorticella marinum
Vorticella sp.
S.C. PENICULINA
F. Parameciidae
Paramecium sp.?
C. PROTOMATEA
F. Colepidae
2 Coleps spp.
F. Metacystidae
Metacystis elongata
Metacystis tesselata
Pelatractus grandis
F. Prorodontidae
Prorodon sp.
C. LITOSTOMATEA
F. Amphileptidae
Hemiophrys sp.
Litonotus sp.
Loxophyllum sp.
F. Enchelyidae
Enchelyodon sp.
F. Lacrymariidae
Lacrymaria olar
Lacrymaria coronata
2 Lacrymaria spp.

PHYLUM HELIOZOA
C. ACTINOPHRYIDEA
O. Actinophyrida
F. Actinophryidae
Actinophrys sol
Actinophrys vesiculata

KINGDOM ANIMALIA
SUBK. PHAGOCYTELLOZOA

PHYLUM PLACOZOA
Trichoplax adherens

SUBKINGDOM PARAZOA

PHYLUM PORIFERA
5 unidentified spp.
C. DEMOSPONGIAE
O. Homosclerophorida
F. Plakinidae
Plakina sp.
1 unidentified sp.?
O. Astrophorida
F. Geodiidae
2 Erylus spp.
Geodia gibberosa?
2 Geodia spp.
F. Pachastrellidae
Dercitus sp.
O. Spirophorida
F. Tetillidae
Cinachyrella sp.
O. Hadromerida
F. Suberitidae
Laxosuberites sp.
F. Spirastrellidae
Timea sp.
Spirastrella sp.
F. Clionidae
Cliona caribbaea?
2 Cliona spp.
Thoosa sp.
F. Tethyidae
Tethya actinia
Tethya sp.
F. Chondrosiidae
Chondrilla sp.
O. Axinellida ?
F. Axinellidae ?
1 unidentified sp.
O. Agelasida
F. Agelasidae
Scopalina sp.
O. Haplosclerida
F. Haliclonidae
Haliclona tubulifera
Haliclona cf. toxadocia
2 Haliclona spp.
F. Oceanapiidae
Oceanapia fistulosa
O. Poecilosclerida
F. Mycalidae
Mycale sp.
O. Halichondrida
F. Dexmoxyidae
Myrmekioderma sp.?
F. Halichondridae
2 Halichondria sp.?
C. CALCAREA
O. Clathrinida
F. Clathrinidae
Clathrina sp.
O. Leucettida
F. Leucettidae
Leucetta sp.
2 unidentifed spp. incerti-sedis

SUBKINGDOM EUMETAZOA

PHYLUM CNIDARIA
C. HYDROZOA
3 unidentified spp.
O. Hyroida

- F. Eudendridae
  - *Eudendrium sp. ?*
- F. Olindiiae
  - *Microhydrula sp.*

C. ANTHOZOA

- **O. Gorgonacea**
  - F. Plexauridae
    - *Eunicea sp.*
  - F. Anthothelidae
    - *Erythropodium caribaeorum*
  - F. Briareum
    - *Briareum asbestinum*
- **O. Alcyonacea**
  - F. Alcyoniidae
    - *Sarcophyton trocheliophorum**
    - *Sinularia sp.**
- **O. Actinaria**
  - F. Actiniidae
    - *Anthopleura krebsi*
    - *Anthopleura sp.*
    - *Condylactis gigantea*
  - F. Aiptasiidae
    - *Aiptasia sp.*
  - F. Stichodactylidae
    - *Stichodactyla helianthus*
- **O. Corallimorpharia**
  - F. Actinodiscidae
    - *Rhodactis sanctithomae*
    - *2 Discosoma spp.*
    - *Orinia sp.*
  - F. Corallimorphidae
    - *Corynactis parvula*
    - *Corynactis sp.*
    - *Ricordea florida*
- **O. Scleractinia**
  - F. Acroporidae
    - *Acropora sp.**
    - *Montipora digitata **
  - F. Caryophylliidae
    - *Physogyra sp.**
  - F. Faviidae
    - *Montastrea cavernosa*
    - *Diploria clivosa*
    - *Diploria labyrinthiformis*
  - F. Mussidae
    - *Isophyllia sp.*
  - F. Poritidae
    - *Porites porites*
    - *Porites divaricatus*
    - *Porites asteroides*
- **O. Zoanthinaria**
  - F. Zoanthidae
    - *Palythoa caribaeorum*
    - *2 Zoanthus spp.*
- **O. Ceriantharia**
  - 1 unidentified sp.

PHYLUM PLATYHELMINTHES

- **O. Acoela**
  - F. ?
    - *Amphiscolops sp.*
  - F. Anaperidae
    - *2 Anaperus spp.*
    - *Convoluta sp.*
- **O. Nemertodermatida**
  - F. Nemertodermatidae
    - *Nemertoderma sp.*
- **O. Kalyptorhychia**
  - *Gyrotrix sp.*

PHYLUM NEMERTEA

C. ANOPLA

- **O. Palaeonemertea**
  - 1 unidentified sp. (new?)
- **O. Heteronemertea**
  - 1 unidentified sp.
  - F. Micruridae
    - *Micrura vanderhosti*
  - F. Lineidae
    - *Lineus albocinctus?*

PHYLUM GASTROTRICHA

- F. Chaetonotidae
  - *Chaetonotus sp.*
  - 1 unidentified sp.

PHYLUM ROTIFERA

- 2 unidentified spp.

PHYLUM TARDIGRADA

- F. Batillipedidae
  - *Batillipes sp.*

PHYLUM NEMATA (Nematodes)

- F. Draconematidae
  - *Dracograllus sp.*
  - 2 unidentified spp.

PHYLUM MOLLUSCA

C. POLYPLACOPHORA

- **O. Acanthochitonida**
  - F. Acanthochitonidae
    - *Acanthochitona pygmaea*

C. GASTROPODA

- **O. Archaeogastropoda**
  - F. Fissurellidae
    - *Diadora sp.*
    - *Rimula sp.*
  - F. Acmaeidae
    - 1 unidentified sp.
  - F. Trochidae
    - *Calliostoma sp.*
  - F. Turbinidae
    - *Turbo canicularia*
  - F. Phasianellidae
    - *Tricolia bella*
  - F. Neritidae
    - *Smaragdia viridis*
- **O. Mesogastropoda**
  - F. Rissoidae
    - *Rissoina sp.*
  - F. Rissoellidae
    - 1 unidentified sp.
  - F. Vitrinellidae
    - 1 unidentified sp.
  - F. Vermetidae
    - *Petalochoncus varians*
  - F. Phyramidellidae
    - 1 unidentified sp.
- **O. Neogastropoda**
  - F. Fasciolariidae
    - *Latirus sp.*

Fasciolaria hunterii
F. Olividae
1 unidentified sp.
F. Marginellidae
Volvarina albolineata
F. Mitridae
1 unidentified sp.
O. Cephalaspidea
F. Bullidae
Bulla sp.
3 unidentifed spp. incerti-sedis
C. BIVALVIA
1 unidentified sp.
O. Mytiloida
F. Mytilidae
Lithophaga antillarum
Lithophaga bisulcata
O. Arcoida
F. Arcidae
Barbatia domingensis
Barbatia canallaria
F. Glycymerididae
Glycymeris pectinata
O. Pterioida
F. Isognomonidae
Isognomon radiatus
O. Limoida
F. Limidae
Limea bronniana
O. Ostreoida
F. Pectinidae
1 unidentified sp.
O. Hippuritoida
F. Chamidae
Chama sinuosa
O. Veneroida
F. Lucinidae
Lucina sp.
Codakia orbicularis
F. Carditidae
1 unidentified sp.
F. Tridacnidae
*Tridacna maxima**
*Tridacna derasa**
F. Tellinidae
Tellina listeri

PHYLUM ANNELIDA
C. POLYCHAETA
O. Phyllodocida
F. Syllidae
Haplosyllis spongicola
Amblyosyllis speciosa?
1 unidentified sp.
O. Amphinomida
F. Amphinomidae
Pareurythoe sp.
O. Eunicida
F. Eunicidae
Nematonereis sp.
3 unidentified sp.
F. Lumbrineridae
Lumbrineris sp.
F. Dorvilleidae
1 unidentified sp.
O. Orbiniida
F. Orbiniidae
1 unidentified sp.
O. Spionida
F. Spionidae
1 unidentified sp.
O. Chaetopterida
F. Chaetopteridae
Phyllochaetopterus sp.
O. Cirratulida
F. Paraonidae
Cirrophorus sp.
F. Cirratulidae
Timarete sp.
Cirriformia sp.
2 unidentified spp.
O. Ctenodrilida
F. Ctenodrilidae
Ctenodrilus serratus
O. Capitellida
F. Capitellidae
Neoheteromastus sp.
Scyphoproctus sp.
Capitella sp.
F. Maldanidae
Euclymene sp.
O. Oweniida
F. Oweniidae
1 unidentified sp.
O. Terebellida
F. Terebellidae
2 Thelepus spp.
O. Sabellida
F. Sabellidae
2 Notaulax spp.
3 Bispira spp.
8 unidentified spp.
S.F. Fabriciinae
New Genus (to be described)
F. Serpulidae
Vermiliopsis cf. annulata
Semivermilia pomatostegoides
Pomatostegus stellatus
Spiraserpula caribensis
Hydroides gairacensis
Salmacinopsis setosa ?
F. Spirorbidae
Vinearia koehleri
Janua pagenstecheri (epichysis)
O. Dinophilida
F. Dinophilidae
Dinophilus sp.

PHYLUM SIPUNCULA
F. Golfingiidae
Golfinigia sp. ?
F. Phascolosomatidae
Apionsoma misakianum
Phascolosoma perlucens
Phascolosoma nigrescens
F. Phascolionidae
Phascolion gerardi
F. Aspidosiphonidae
Lithocrosiphon cristatus
Aspidosiphon laevis
Aspidosiphon fischeri

PHYLUM ARTHROPODA
C. ARACHNIDA

O. Acariformes
F. Halacaridae
Halacarid mite
C. CRUSTACEA
S.C. OSTRACODA
O. Podocopnia
2 unidentified spp.
F. Cyprididae
Argilloecia sp.
Paracypris sp.
F. Bairdiiae
Bairdia hirsuta
F. Paradoxostomatidae
Paradoxostoma sp.
S.C. COPEPODA
O. Calanoida
F. Pseudocyclopidae
Pseudocylops sp.
F. Ridgewayiidae
Ridgewayia gracilis
Ridgewayia sp.
O. Harpacticoida
F. Ambunguipedidae
Ambunguipes sp.
F. Argestidae
1 unidentified sp. (new)
F. Diosaccidae
Amphiascoides sp.
F. Harpacticidae
Harpacticus sp.
F. Louriniidae
Lourinia sp.
F. Thalestridae
Dactylopusia sp.
F. Tisbidae
Tisbe sp.
S.C. MALACOSTRACA
O. Mysidacea
F. Mysidae
Heteromysis sp.
O. Tanaidacea
F. Apseudidae
2 *Apseudes* nspp.
F. Paratanaidae
Leptochelia dubia
F. Tanaidae
1 unidentified sp. (new)
O. Isopoda
F. Paranthuridae
Accalathura setosa
F. Sphaeromatidae
Paracereis caudata
F. Stenetriidae
Stenetrium stebbingi
F. Janiridae
Carpias algicola
O. Amphipoda
F. Lysianassidae
Shoemakerella sp.
F. Gammaridae
Cerodocus sheardi
Maera sp.
Elasmopus sp.
Parelasmopus sp. ?
F. Leucothoidae
Leucothoe sp.
F. Anamixidae
Anamixis sp.
F. Corophiidae
Bemlos sp.
F. Amphithoidae
Ampithoe ramondi
Cymadusa sp.
O. Decapoda
F. Alpheidae
Alpheus normanni
Snyalpheus townsendi
F. Hippolytidae
Thor dobkini
Thor amboinensis
F. Nephropidae
*Enoplometopus occidentalis**
F. Diogenidae
Clibanarius tricolor
F. Xanthidae
Lobopilumnus agassizii
1 unidentified sp.

PHYLUM ECHINODERMATA
C. STELLEROIDEA
O. Ophiurida
F. Ophiocomidae
Ophiocoma echinata
F. Ophiactidae
Ophiactus sp.
C. ECHINOIDEA
O. Cidaroida
F. Cidaroidae
Eucidaris tribuloides
O. Temnopleuroida
F. Toxopneustidae
Lytechinus variegatus
C. HOLOTHURIIDAE
O. Aspidochirotida
F. Holothuriidae
Holothuria floridana
O. Apodida
F. Chiridotidae
Chiridota rotifera

PHYLUM CHORDATA
SUBPHYLUM TUNICATA
C. ASCIDIACEA
1 unidentified sp.

SUBPHYLUM VERTEBRATA
C. OSTEICHTHES
O. Perciformes
F. Grammidae
Gramma loreto
F. Chaetodontidae
Holocanthus tricolor
F. Pomacentridae
*Chromis caeruleus**
Chromis insolata
*Amphiprion percula**
*Parglyphidodon oxydon**
*Chrysiptera cyanea**
F. Acanthuridae
*Zebrasoma flavescens**

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